Tutorial: Introduction to SMAP

Jet Propulsion Laboratory
California Institute of Technology

Outline

1. *Overview and Mission Objectives*
2. *Description of Instruments (radar and radiometer)*
3. *Review of SMAP Products (soil moisture, freeze/thaw, NEE, root zone soil moisture)*
4. *SMAP calibration/validation*
5. *Application examples*

Overview and Mission Objectives

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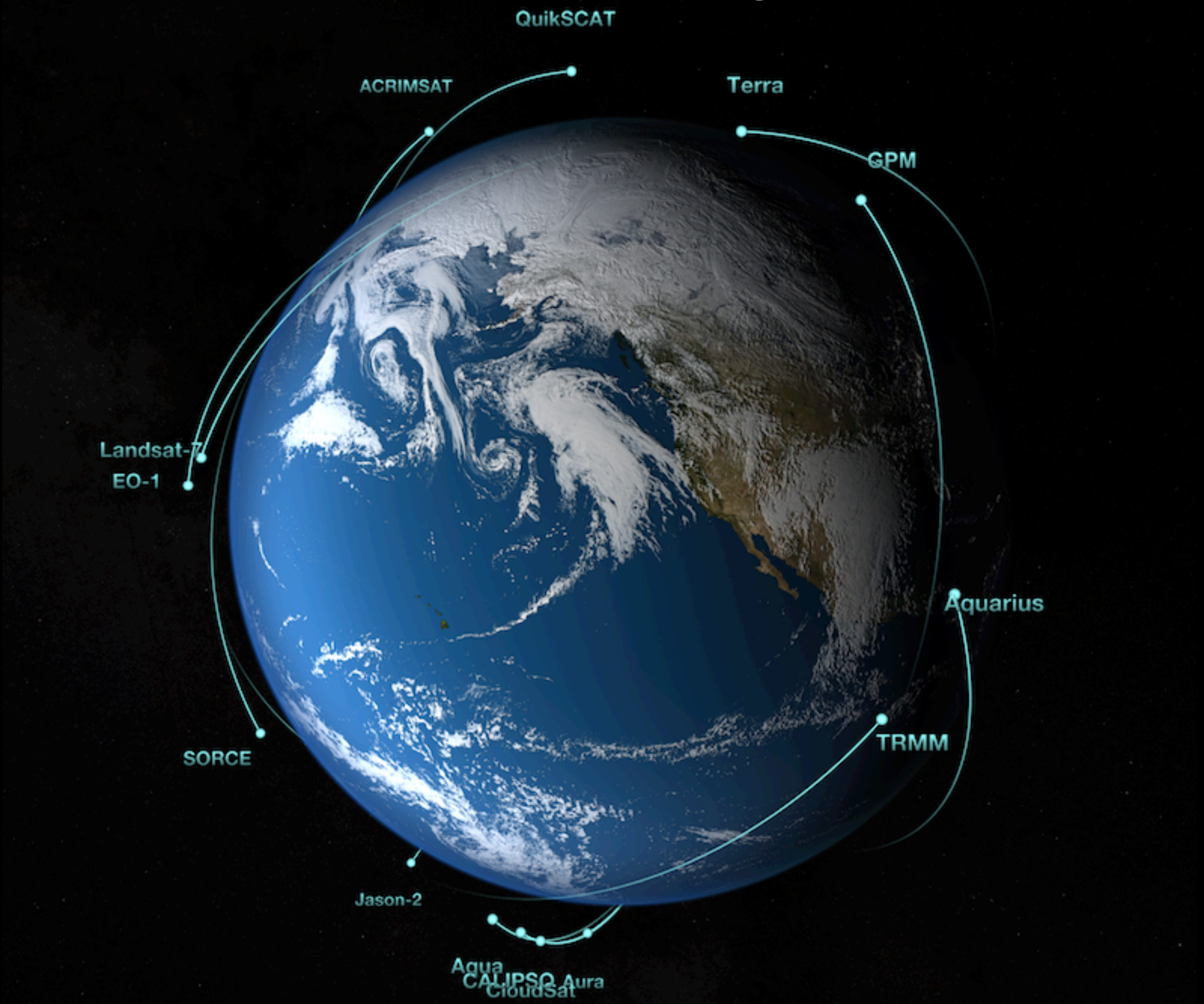
NASA Earth Observing Satellite Fleet



Courtesy of the Goddard Visualization Lab

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SMAP Primary Objectives

SMAP's objective is to provide high-resolution and frequent-revisit global maps of soil moisture and landscape freeze/thaw state.

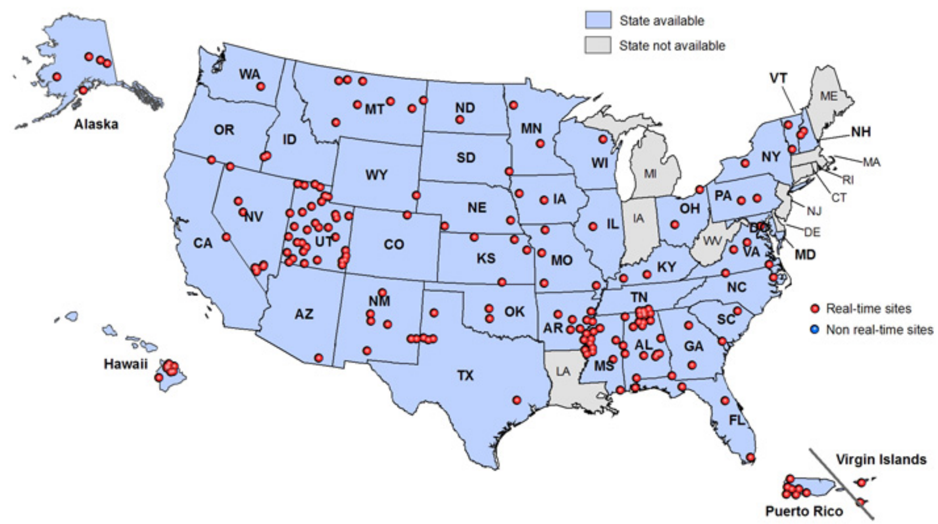
Limitations in measuring global soil moisture:

-current ground measurements of soil moisture are sparse and have limited coverage

-existing space-borne sensors have relatively low sensitivity and resolution

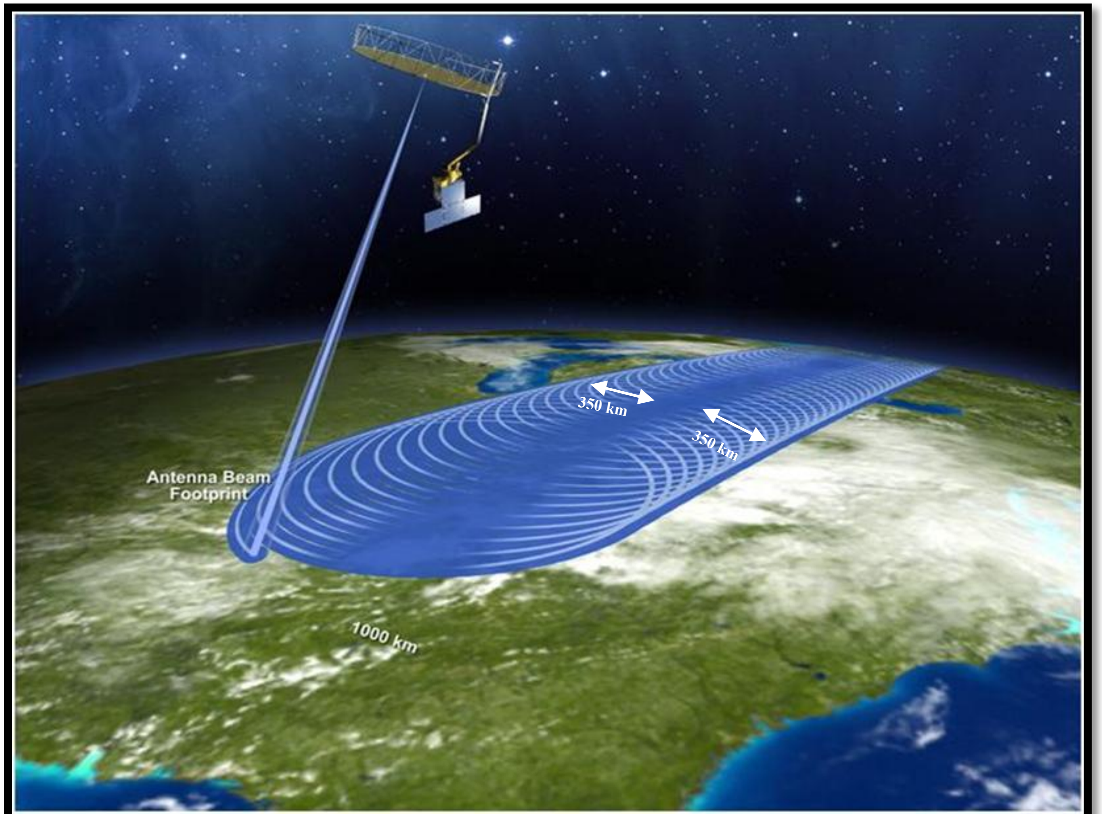
Science and applications addressed by SMAP:

- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather, flood and drought prediction
- Other applications such as agricultural productivity and human health



SMAP Overview

SMAP objective is to provide high-resolution and frequent-revisit global mappings of soil moisture and landscape freeze/thaw state



Launch: Jan. 31, 2015 from Vandenberg Air Force Base in California onboard a Delta II.

SMAP Instrument Configuration

Radar
Frequency: 1.26 GHz
Polarizations: VV, HH, HV
Resolution: 3 km
Relative Accuracy: 1.0 dB (HH and VV), 1.5 dB (HV)

Radiometer
Frequency: 1.41 GHz
Polarizations: H, V, 3rd & 4th Stokes
Resolution: 40 km
Relative Accuracy: 1.3 K

Shared Antenna
6-m diameter deployable mesh antenna
Conical scan at 14.6 rpm
Constant incidence angle: 40 degrees
1000 km-wide swath
Swath and orbit enable 2-3 day global revisit

Orbit
Sun-synchronous, 6 am/pm orbit, **685 km** altitude

Mission Operations
3-year baseline mission

- ***Radar*** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation
- ***Radiometer*** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)
- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science requirements
- Uniqueness: Continuous observations every 2-3 days

SMAP Level 1 Science Requirements

Requirement	Soil Moisture	Freeze/ Thaw
Resolution	**9 and 36 km**	3 km
Refresh Rate	3 days	2 days(1)
Accuracy	**0.04** [cm^3/cm^3] (2)	80% (3)
Duration	36 months	

(1) North of 45°N Latitude
(2) % volumetric water content, 1-sigma
(3) % classification accuracy (binary: Freeze or Thaw)

Product Short Name	Description	Data Resolution
L3_FT_HiRes	Daily Global Composite Freeze/Thaw State	1-3 km
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	36 km
L3_SM_AP	**Daily Global Composite Active-Passive Soil Moisture**	**9 km**
L4_SM	Surface & Root Zone Soil Moisture	9 km
L4_C	Carbon Net Ecosystem Exchange	3 km

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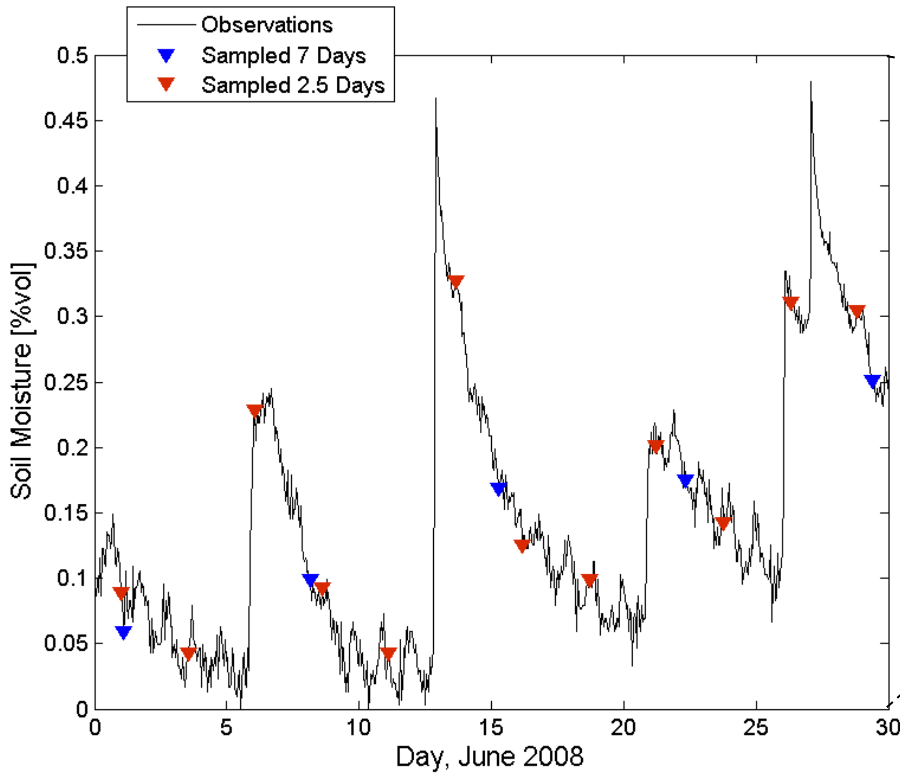
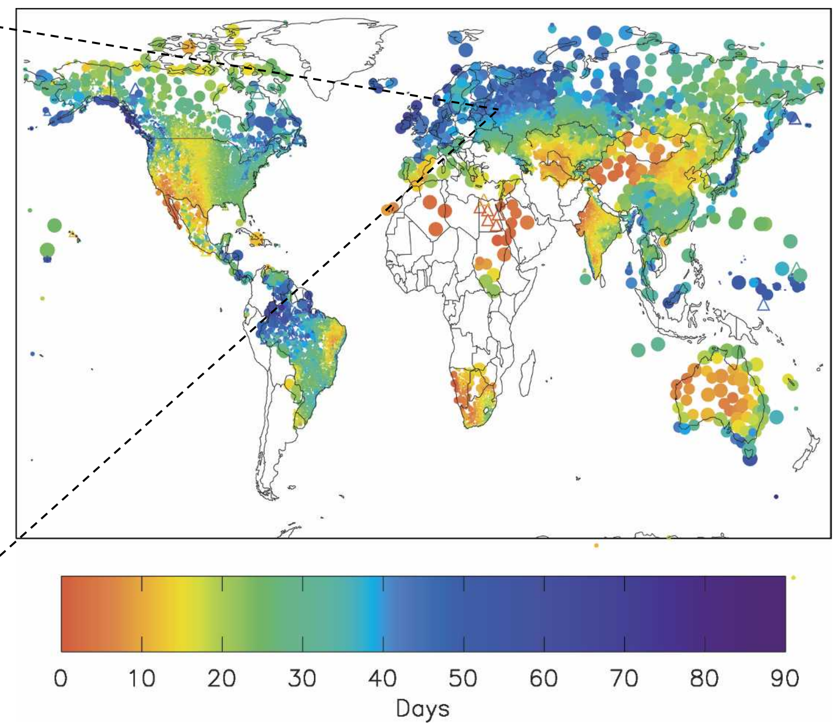
Temporal Revisit

Inter-storm soil moisture dry-down



Global distribution of inter-storm period (# days precipitating per year)



Sun et al. (2006): How often does it rain?, *J. Climate, 19*.

Average inter-storm period => 3-day sampling or better is required to resolve soil moisture variability

SMAP Animation

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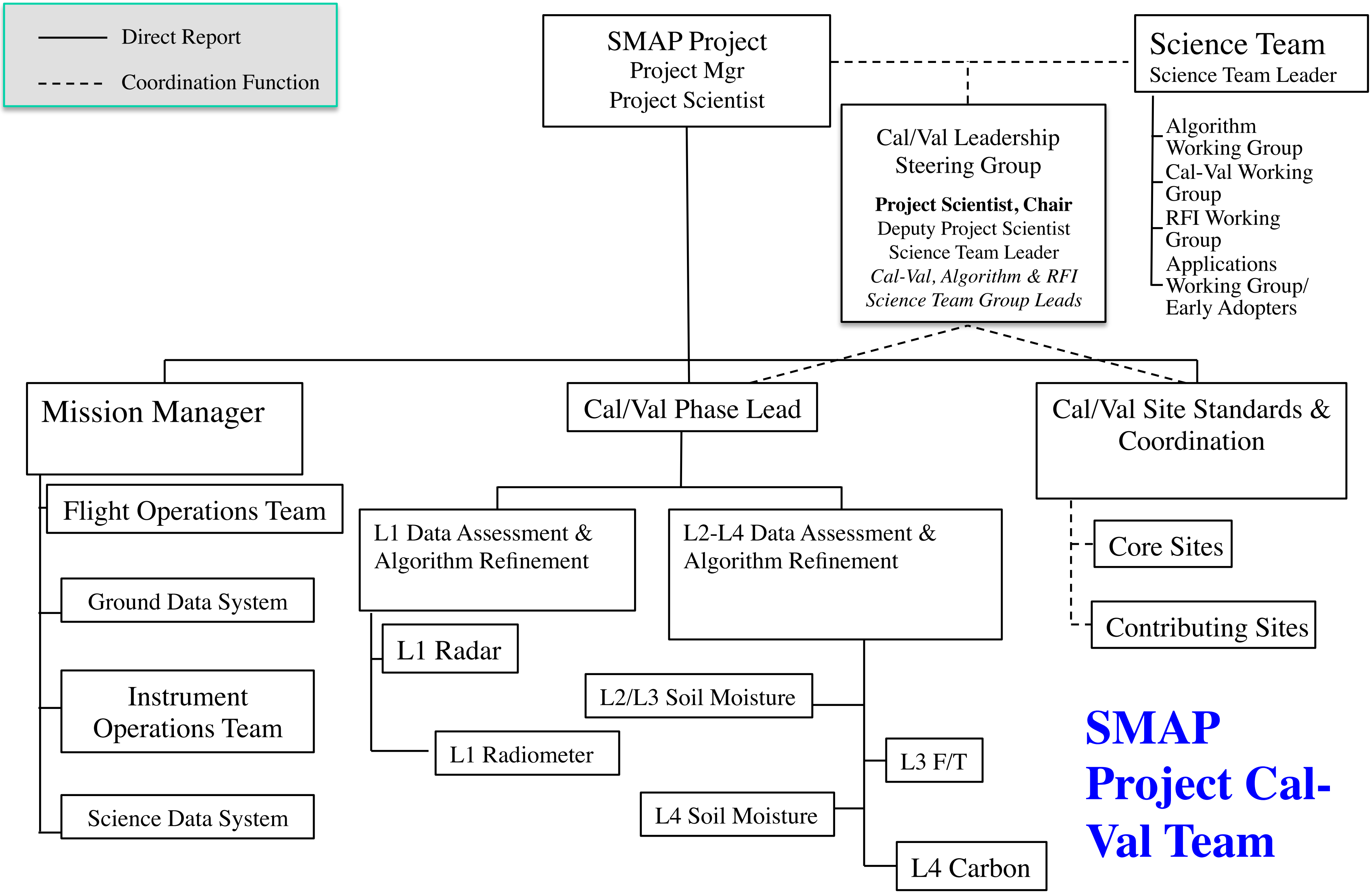
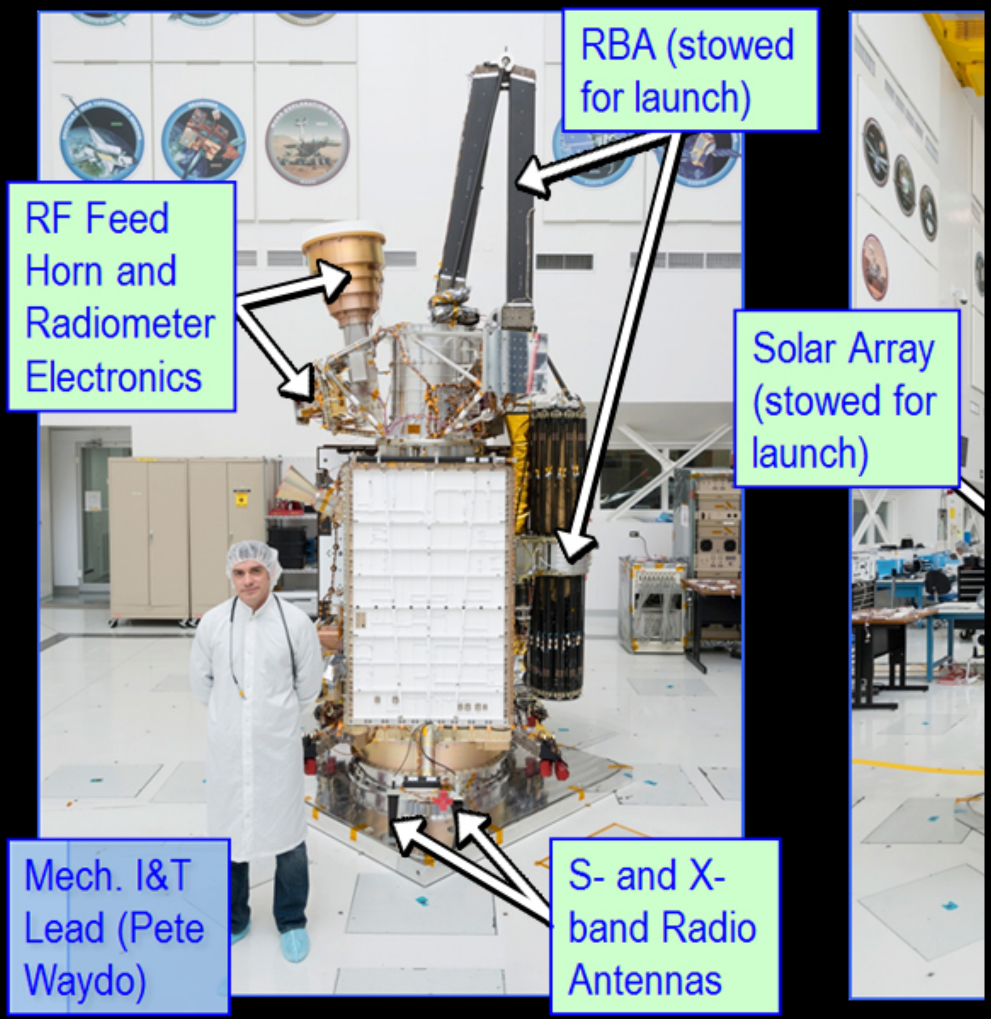
Project Science and CAL/VAL Team

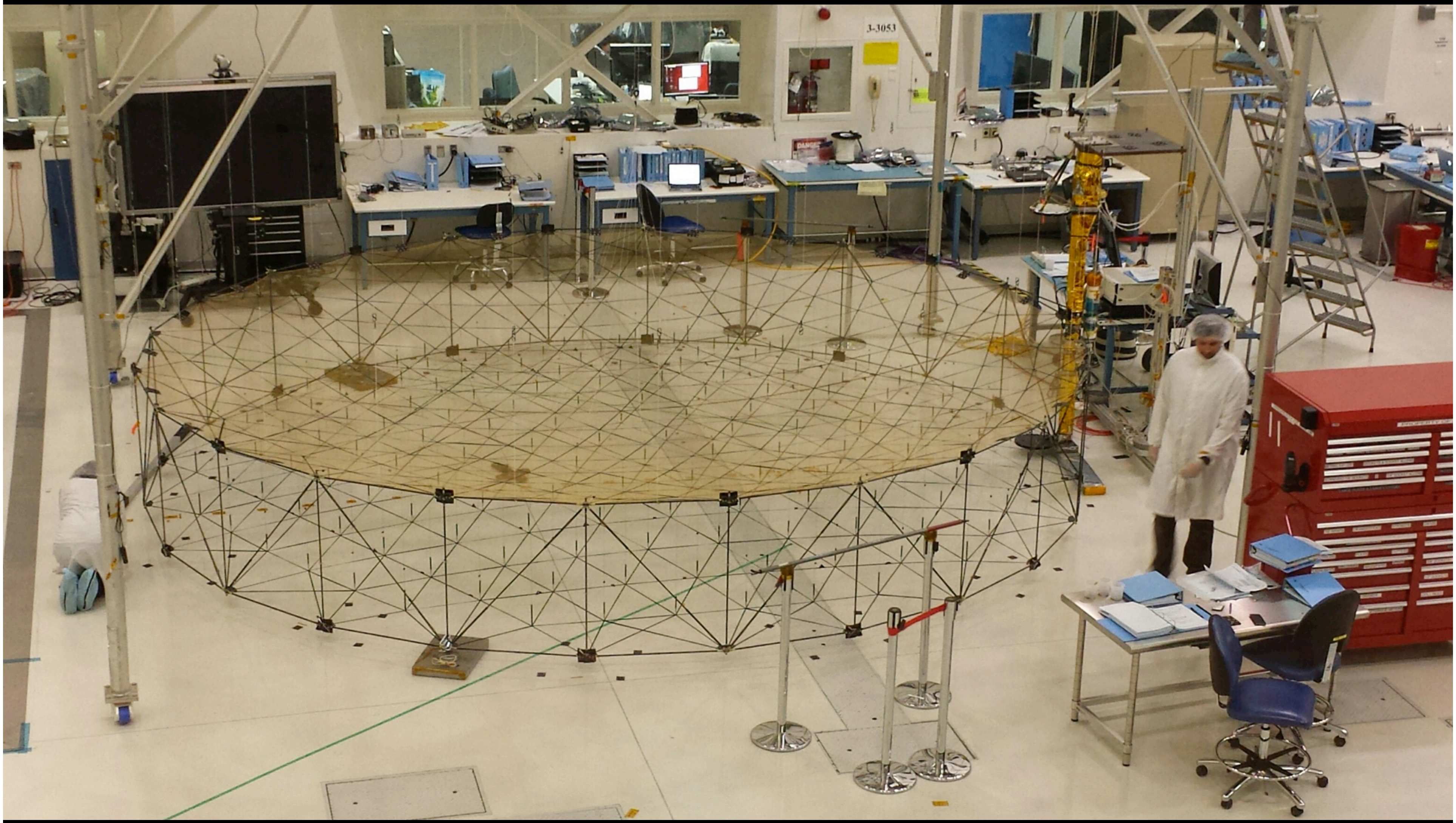


SMAP Spacecraft and Launch Configuration

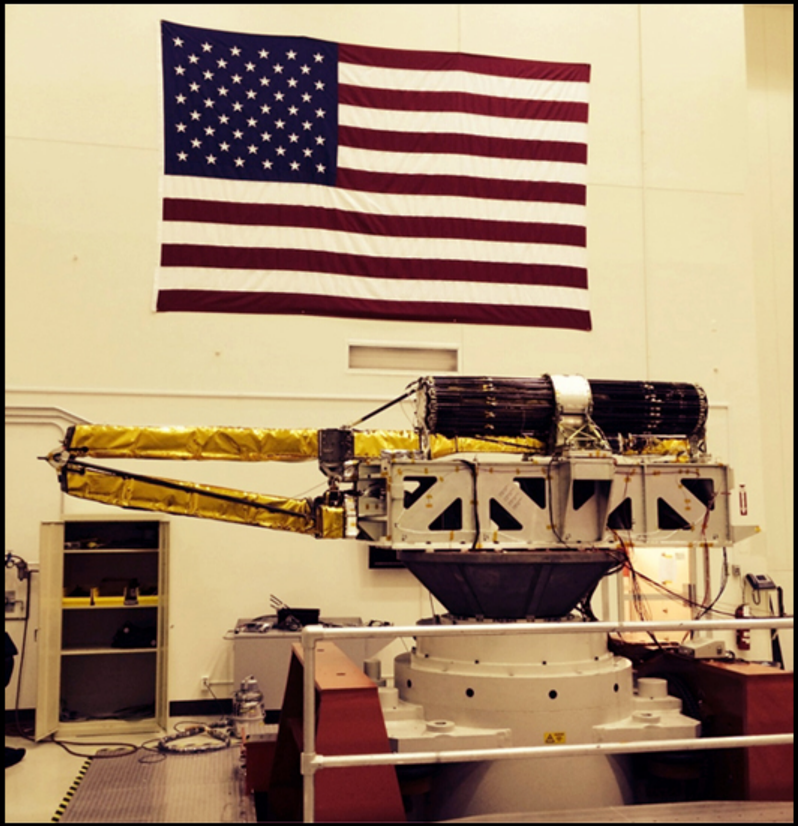
SMAP Spacecraft in Its Launch

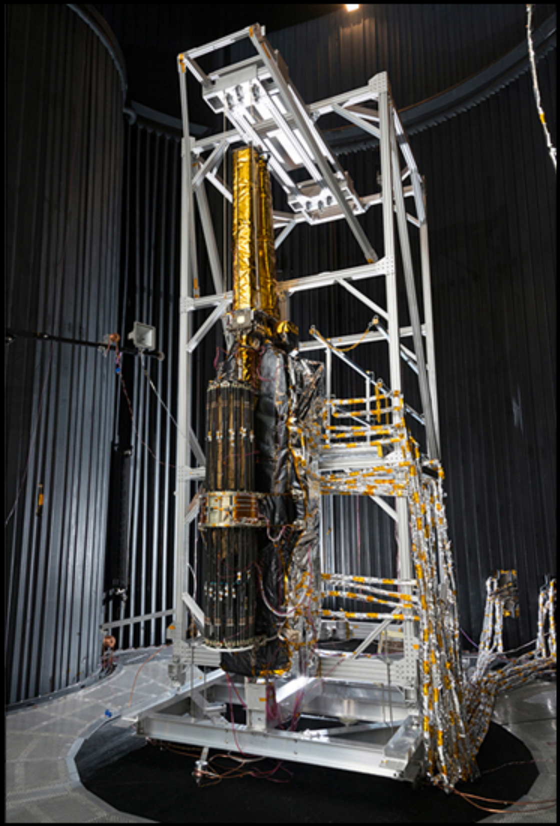


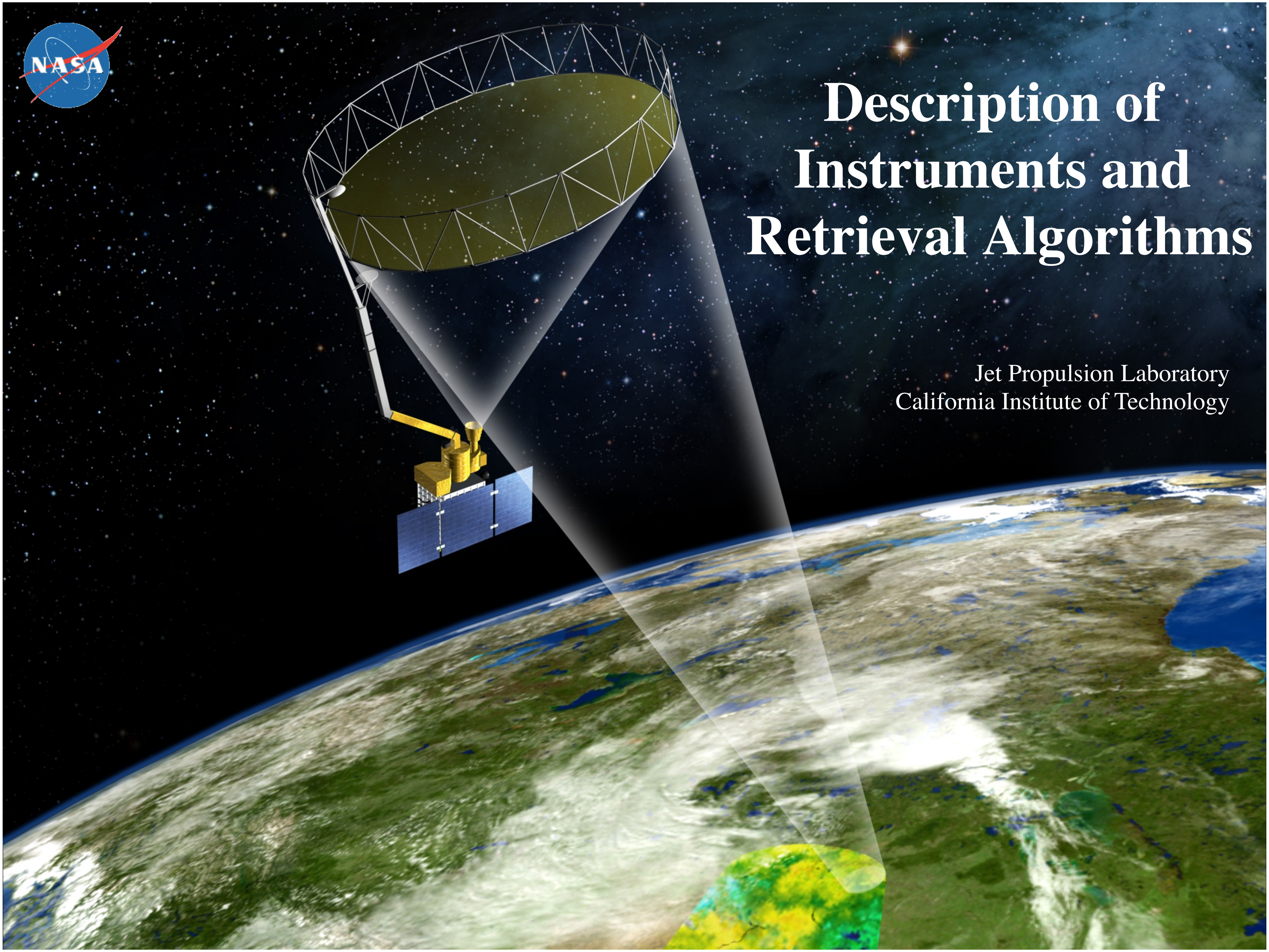
SMAP Antenna



Reflector Boom Assembly Testing to Simulate Launch and Space Environments







Description of Instruments and Retrieval Algorithms

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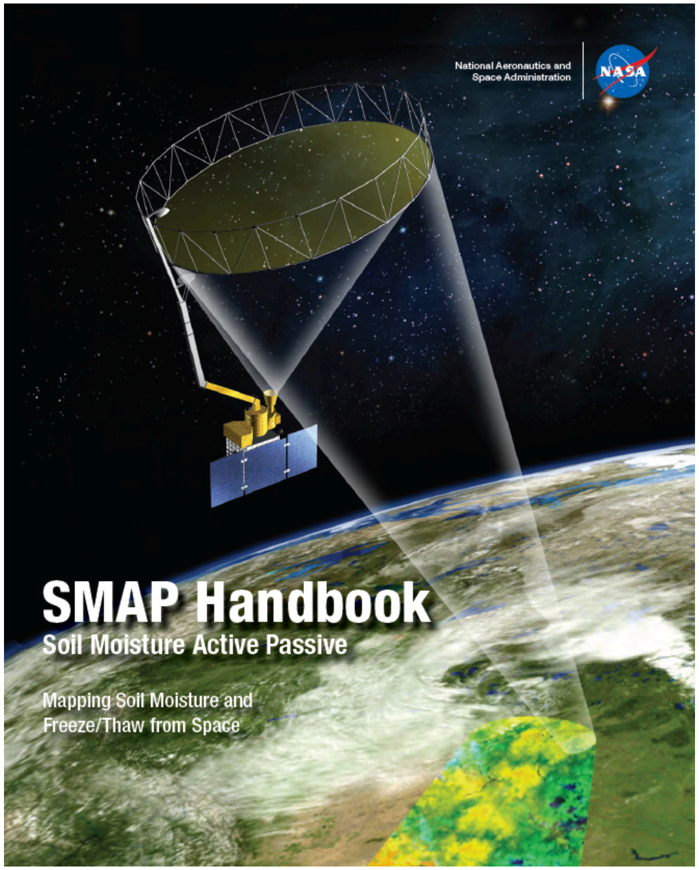
The SMAP Handbook

Chapters

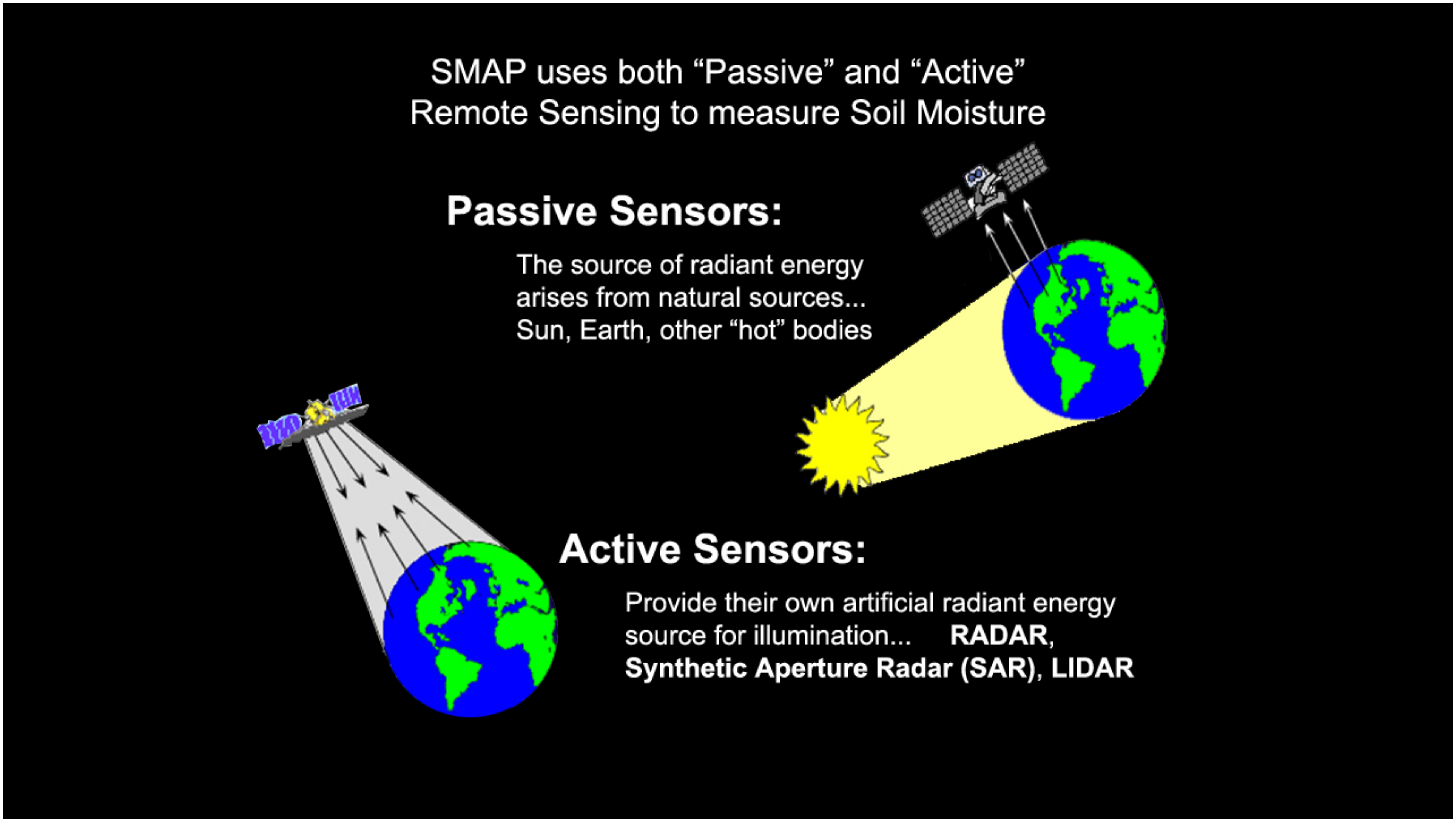
1. Introduction and Background
2. Mission Overview
3. Instrument Design and Data Products
4. Soil Moisture Data Products
5. The Value-Added Data L4_SM Product
6. Carbon Cycle Data Products
7. Calibration and Validation Plan
8. Applications and Applied Science
9. SMAP Project Bibliography



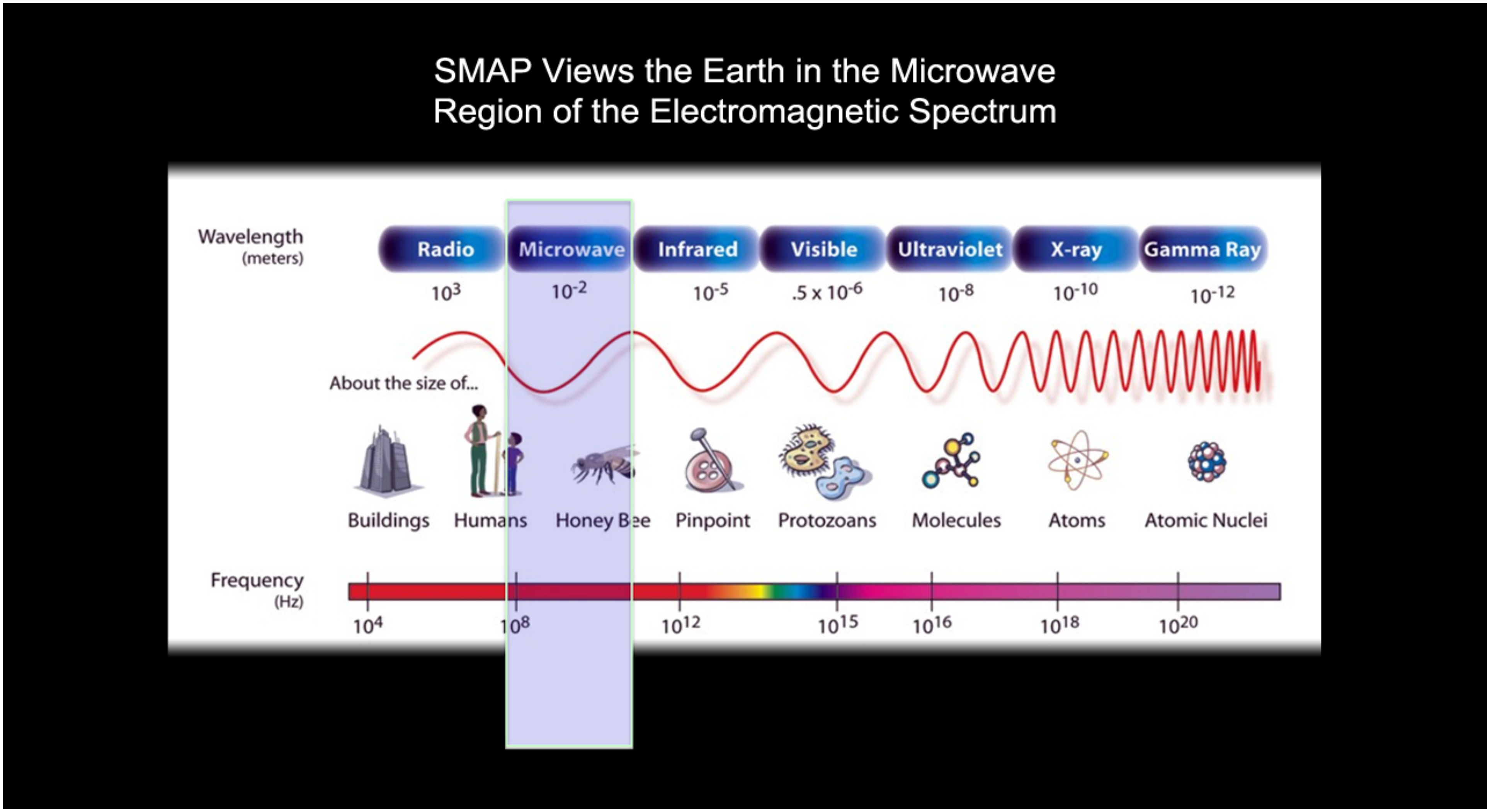
(192 Pages)

http://smap.jpl.nasa.gov/Imperative/

Passive and Active Sensing



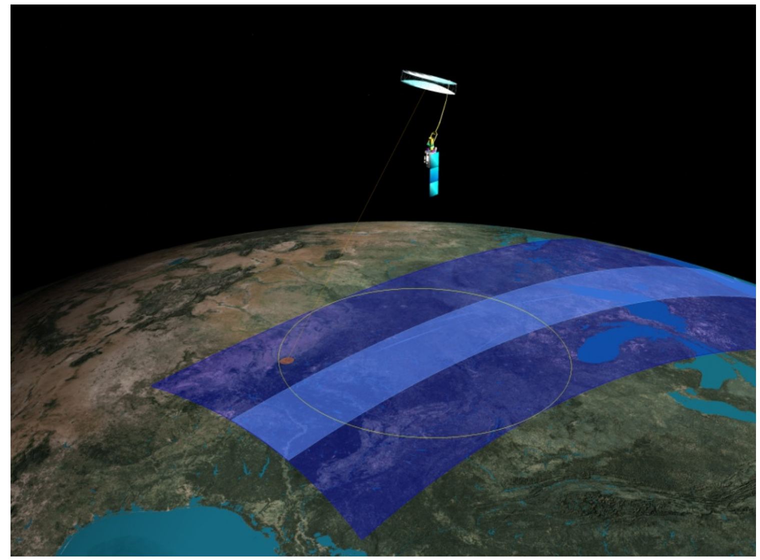
Microwave Sensing



- With Visible and Infrared sensors the soil is masked by clouds and vegetation. Optical sensors operate by measuring scattered sunlight and are “daytime only”.
- Microwaves can penetrate through clouds and vegetation, operate day and night, and are highly sensitive to the water in the soil due to the change in the soil microwave dielectric properties.

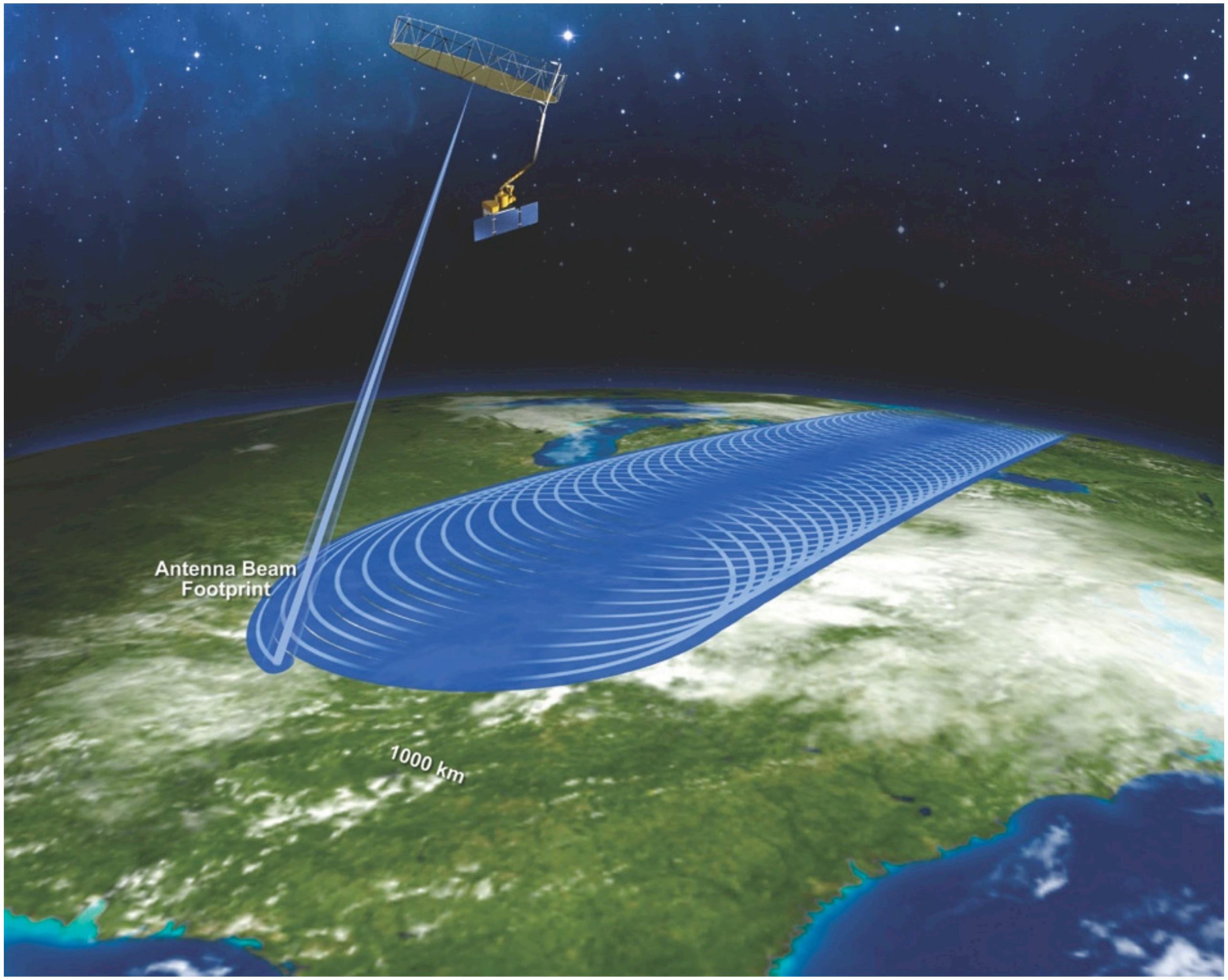
SMAP Mission Concept Overview

- **SMAP has two instruments:**
  - *L-band Radar (1.26 GHz)*
    - *VV, HH, HV (or VH)*
    - *High resolution, moderate accuracy soil moisture*
    - *Freeze/thaw state detection*
    - *SAR mode (non-imaging): 3 km resolution*
    - *Real-aperture mode: 30 x 6 km resolution*
  - *L-band Radiometer (1.4 GHz)*
    - *V, H, 3rd & 4th Stokes parameters*
    - *Moderate resolution, high accuracy soil moisture*
    - *40 km resolution*
  - *Shared antenna*
    - *6-m diameter deployable mesh antenna*
    - *Conical scan at 14.6 rpm*
    - *incidence angle: 40 degrees*
      - *Creates contiguous 1000 km swath*
      - *Swath and orbit enable 2-3 day revisit*

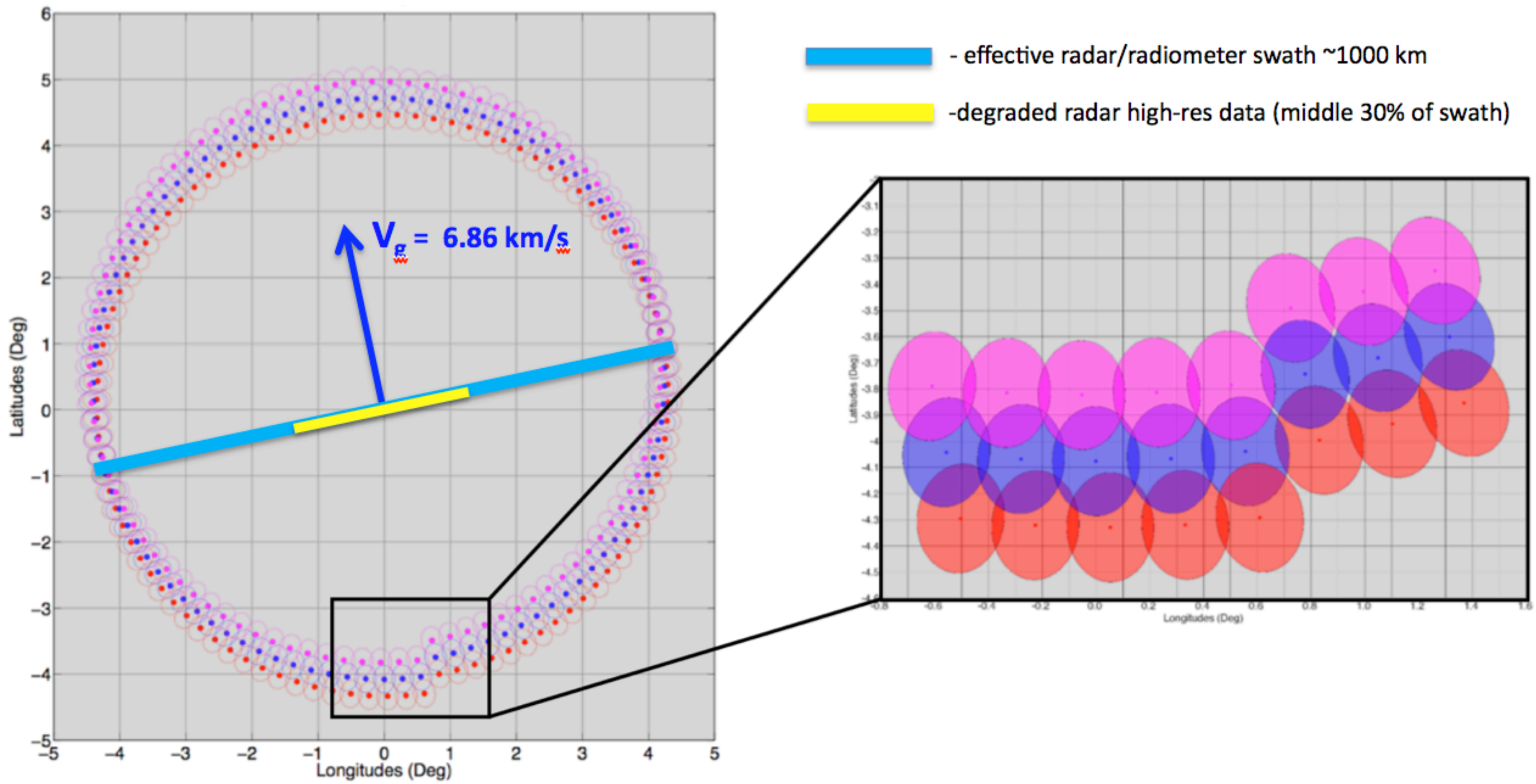


- **Orbit:**
  - *Sun-synchronous, 6 am/pm orbit*
  - *670 km altitude*
- **Mission duration:**
  - *3 years*

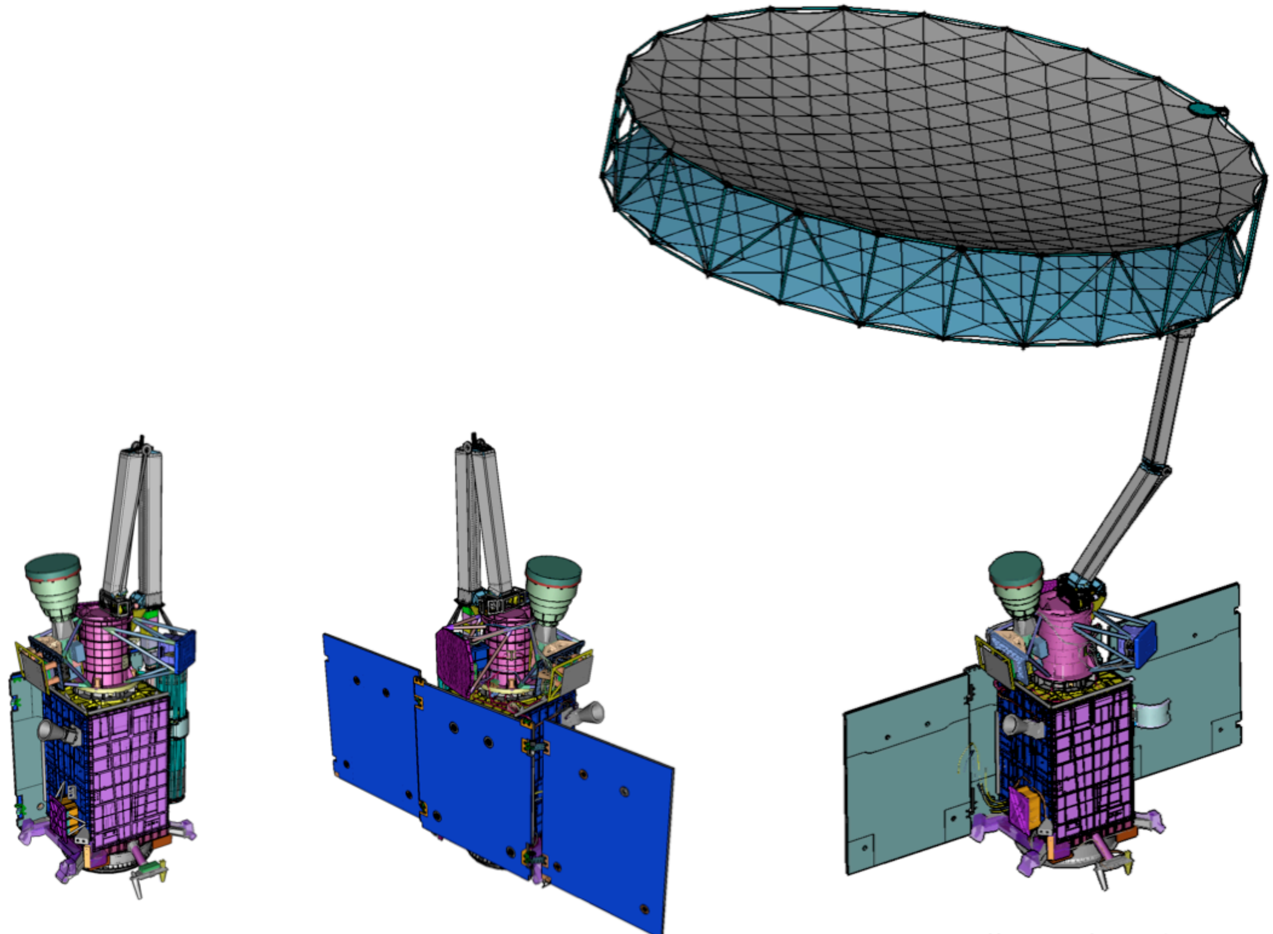
SMAP Antenna Helical Scan Pattern



Overlapping Footprints



Antenna Deployment

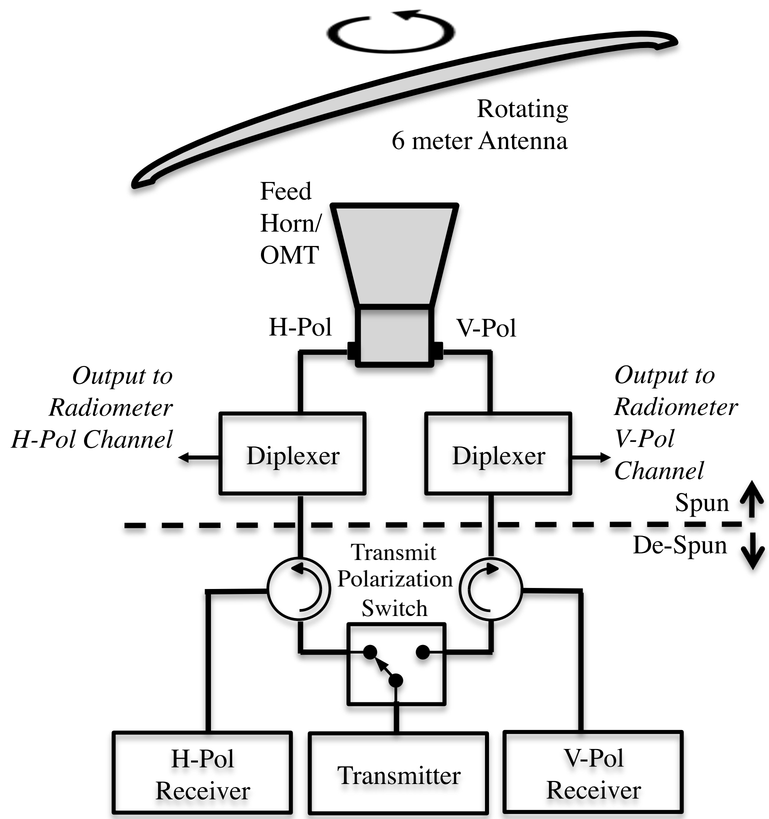


Launch Configuration

Partially Deployed (solar array)

Fully Deployed (solar array and RBA)

Radar and Radiometer Operation



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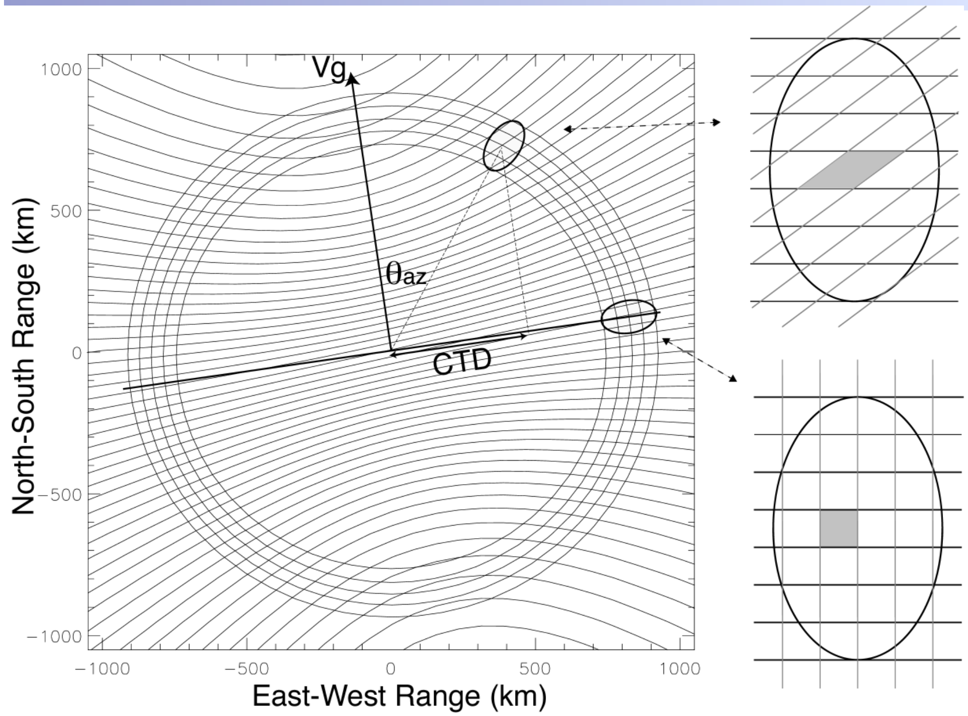
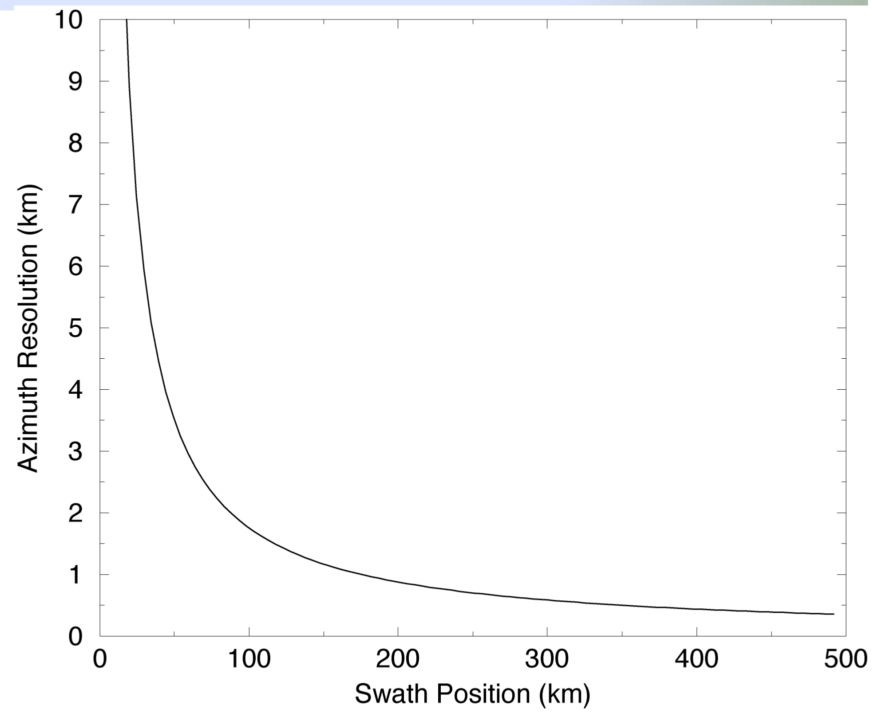
Radar Resolution Enhancement





- Unfocused synthetic aperture radar (SAR) processing.
- Azimuth resolution, and number of azimuth looks, driven by unique scanning geometry.
- High-resolution SAR data that meets science requirements for resolution and accuracy is over outer 70% of the measurement swath.

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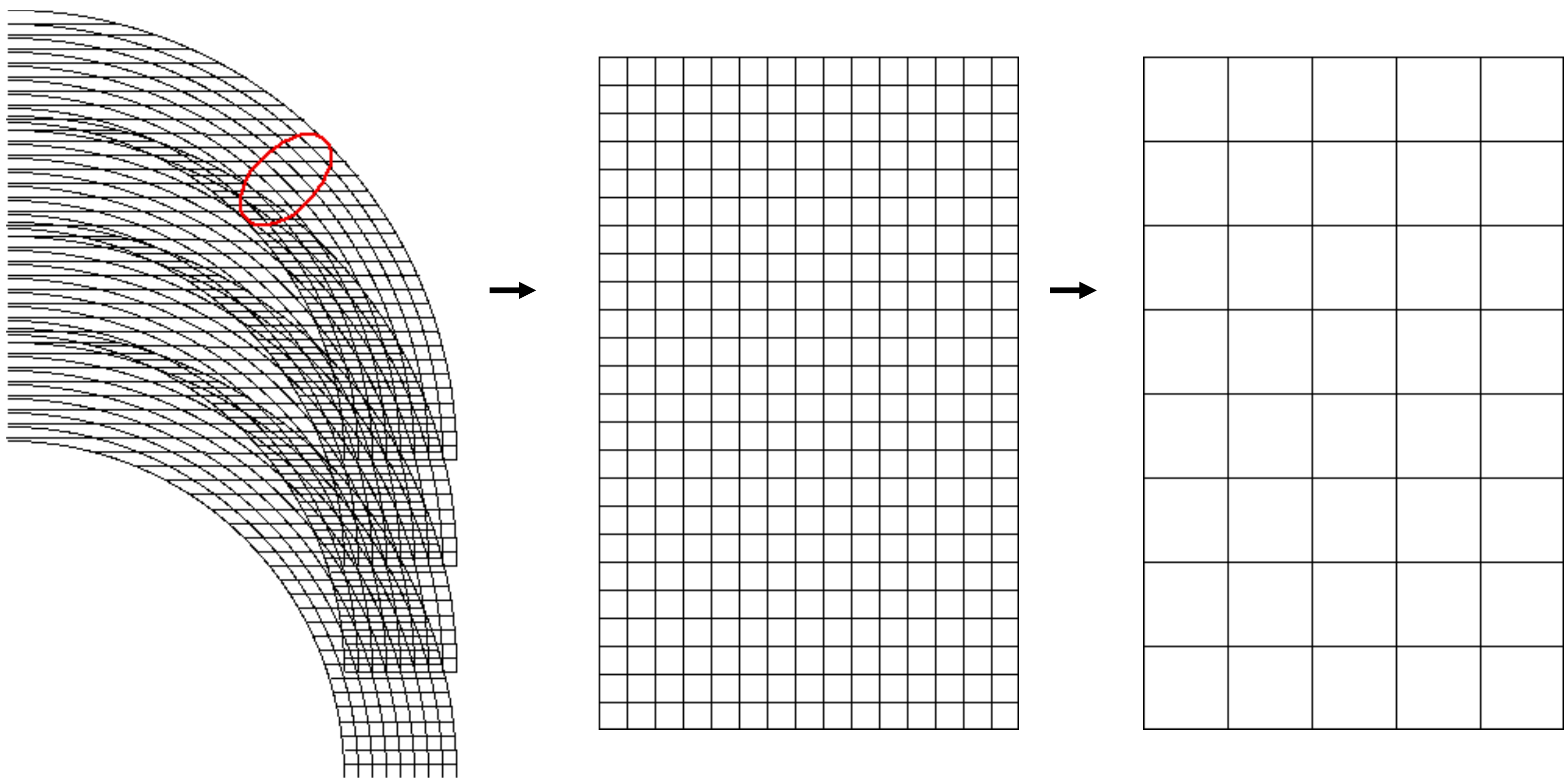
Radar Data Gridding and Averaging (L1B to L1C Processing)



Single-Look, Time-Ordered Data

- Native resolution: 250 m in range, 400+ m resolution in azimuth.
- Each resolution element constitutes one independent "look" at surface.

1 km Gridded, Re-Sampled Data

- Data resampled and posted on 1 km grid, resolution may still be > 1 km near nadir.
- Each resolution cell now has multiple "looks" at surface, decreased measurement variance.

3 km (or whatever) Average Data

- 1 km posted product can be averaged up to 3 km, 10 km, etc. by investigators.
- Improved number of looks (and hence precision) at expense of spatial resolution.

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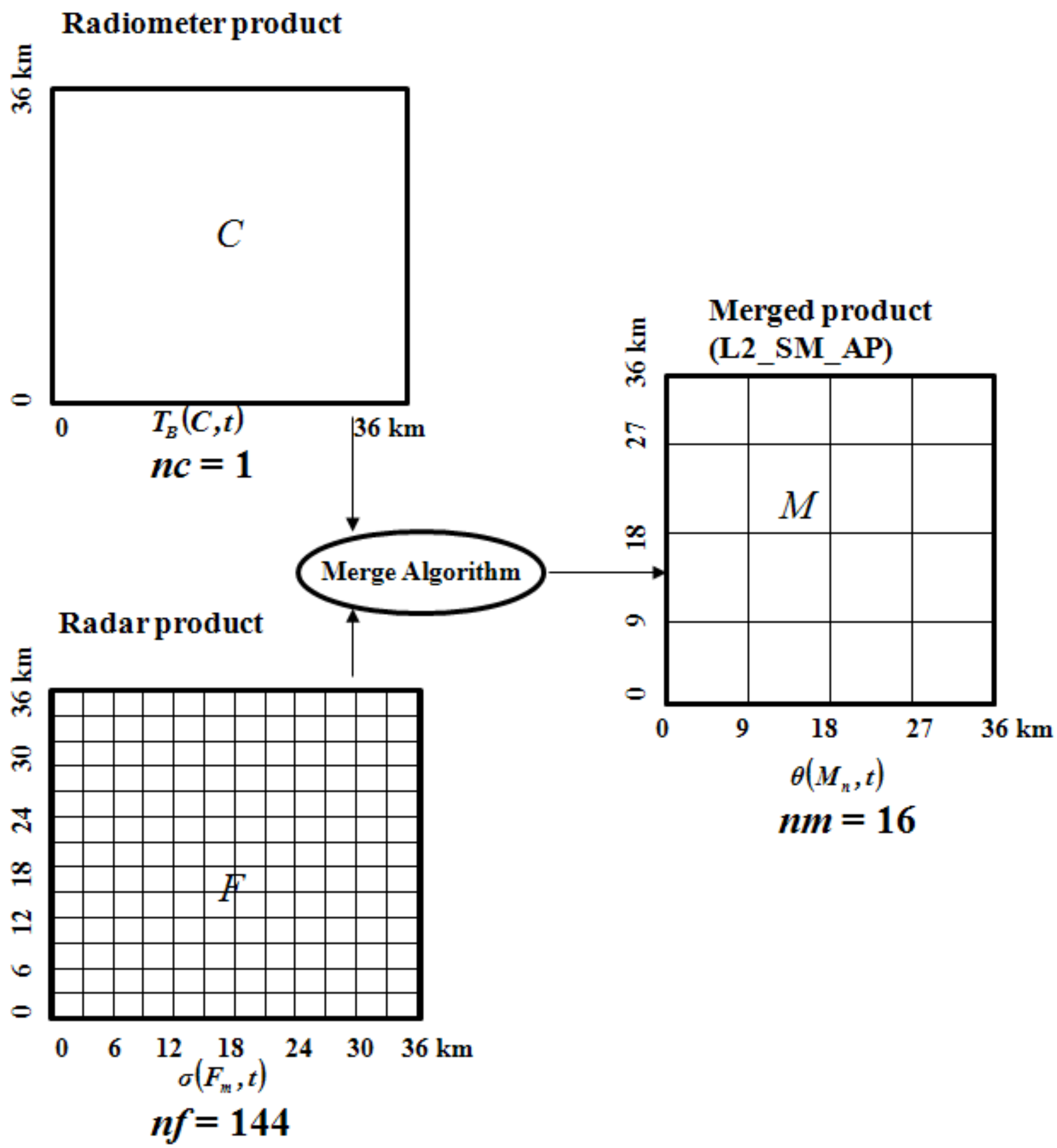
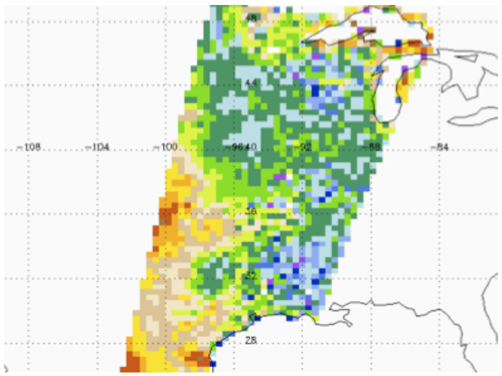
Combined Radar/Radiometer Product

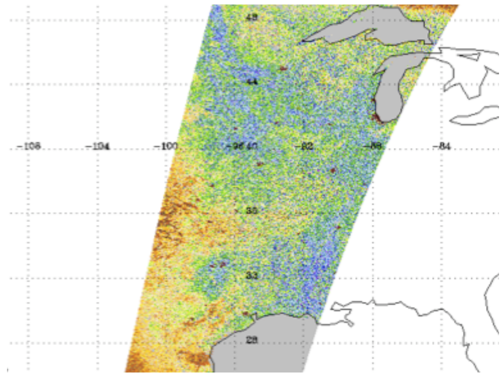


Simulated Level 2 Soil Moisture Products

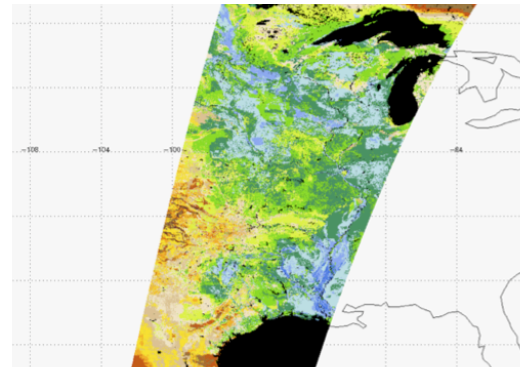
36 km Radiometer
L2_SM_P



3 km Radar
L2_SM_A



9 km Combined
L2_SM_A/P



SMAP has three level 2 (L2) soil moisture products:

- They have been tested through end-to-end simulations: Geophysical data ➞ orbit ➞ observations ➞ errors ➞ inversion.
- Used baseline algorithms – other algorithms are being tested also as options.
- Software is implemented on the SMAP Science Data System (SDS).

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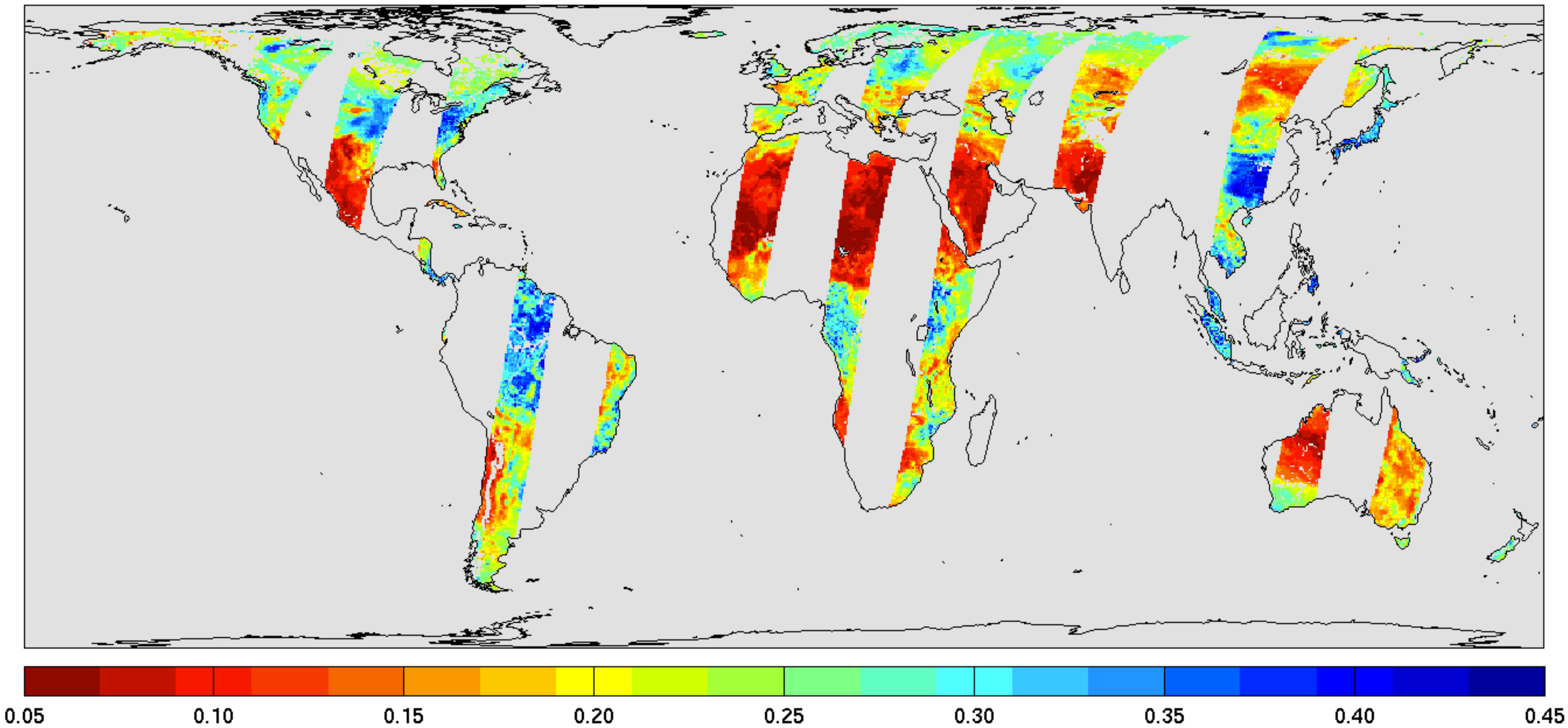
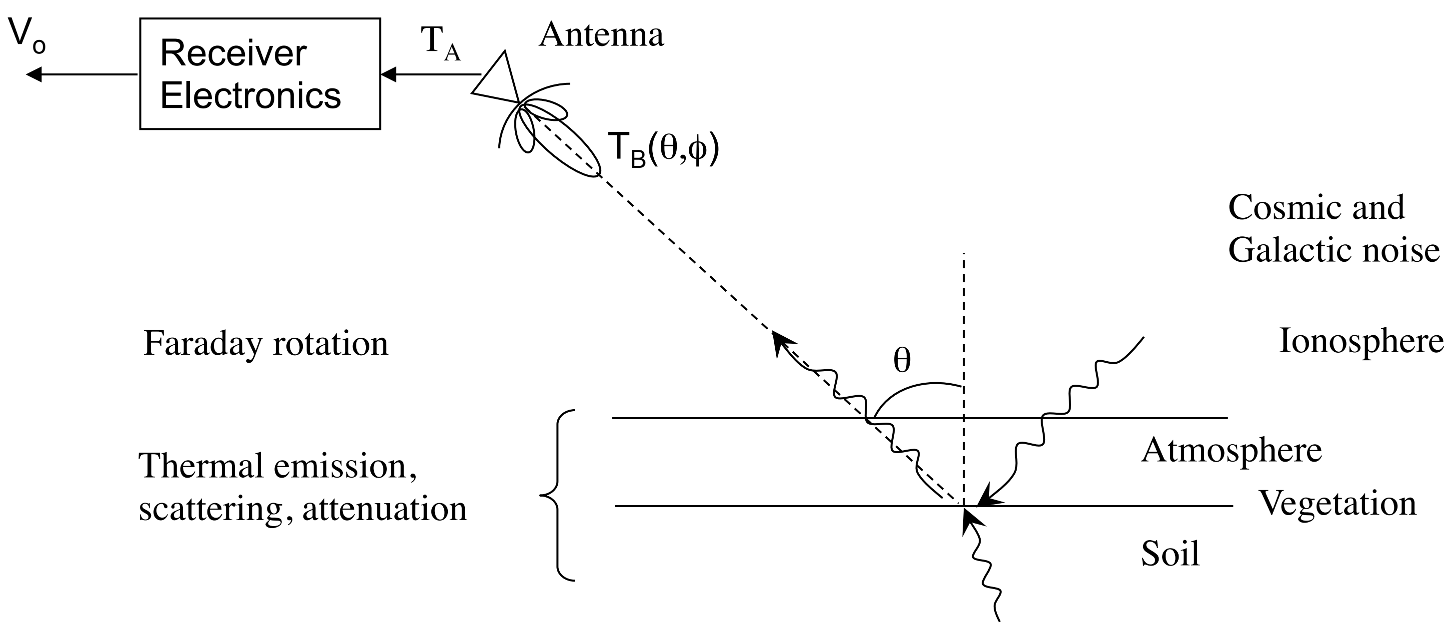
Daily Global Soil Moisture Map (Level 3)



Schematic Observational Configuration (Radiometer)



$T_B(\theta,\phi)$ is the scene brightness temperature (K) $= e(\theta,\phi)T_S$

$e(\theta,\phi)$ is the emissivity, T_S is the physical temperature

T_A is the antenna temperature (K)

V_o is the radiometer output (volts)

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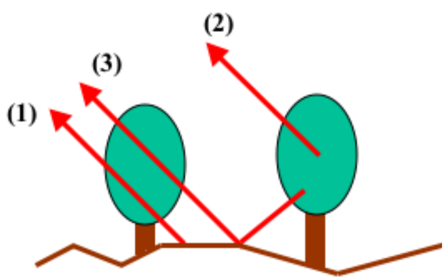
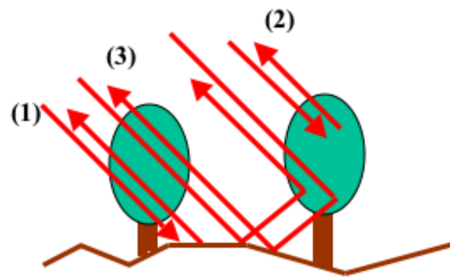
Measurement Approach (Physical Basis)



Emission

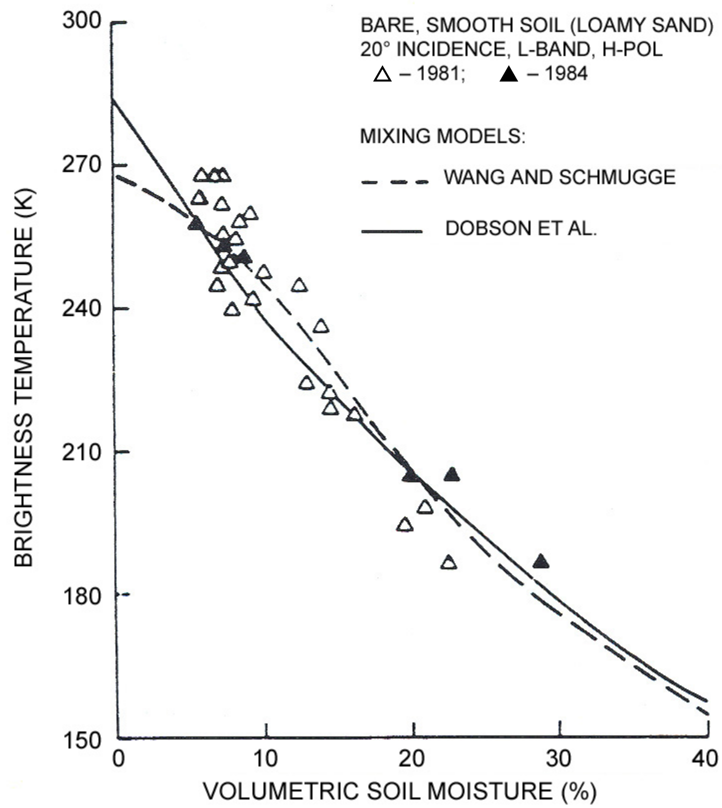


Backscatter

$$T_{Bp}^{t} = T_{Bp}^{s} L_{p} + T_{Bp}^{v} + T_{Bp}^{sv} \qquad \text{(Emission)}$$

$$\sigma_{pq}^{t} = \sigma_{pq}^{s} L_{pq}^{2} + \sigma_{pq}^{v} + \sigma_{pq}^{sv} \qquad \text{(Backscatter)}$$

- Equations for p = H, V (radiometer) and pq = VV, HH, HV (radar)
- Contributions include three terms: soil, vegetation, and soil-vegetation interaction
- Soil moisture is the dominant contributor to the signal
- L is the vegetation attenuation factor, $\exp(-\tau_o / \cos\theta)$
- Retrievals invert these equations to obtain soil moisture, with corrections for vegetation, roughness and surface temperature



[Jackson and O'Neill, *IEEE TGARS*, *GE-25*, 1987.]

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Surface Radiative Transfer Model

(Single-scattering, quasi-specular assumption)

Surface Brightness Temperature:

$$T_{Bp} = T_s \, e_p \exp(-\tau_c) + T_c \, (1 - \omega) \, [1 - \exp(-\tau_c)] \, [1 + r_p \exp(-\tau_c)]$$

- T_s and T_c are temperatures of soil and vegetation (assumed uniform)
- r_p is the soil reflectivity, related to the emissivity by $e_p = (1 - r_p)$.
- τ_c is the vegetation opacity, $\tau_c = b_o \, W / \cos \theta$; b_o is the attenuation coefficient ; W is above-ground vegetation water content (kg m^{-2})
- w is the vegetation single scattering albedo
- r_p is related to the soil dielectric constant ε by the Fresnel equations (with modifications for surface roughness)
- Roughness influences the sensor response primarily through the RMS surface height, exp(-h) factor, with horizontal correlation length as a secondary influence
- Dielectric constant is related to soil moisture content m_v (% volumetric) via dielectric models

Ancillary Data

Ancillary Data Requirements

- Single-channel algorithm has good heritage but requires reliable ancillary data
- Ancillary data are used to estimate the key unknown parameters: surface temperature (≈ surface air temp. at 6 am), vegetation opacity, surface roughness and soil texture

Ancillary Data Sources

Parameter	Description/Sources
Surface air meteorology	- Data assimilation (GEOS/DAO) - Forecast models (NCEP and ECMWF)
Vegetation opacity	- Vis/IR satellite-derived NDVI, LAI, landcover (MODIS, IGBP-DIS) - Historical phenology (AVHRR)
Surface topography	- Digital elevation models (USGS and SRTM)
Soil texture	- Soils databases (Global, NGDC; US, STATSGO)
Land/water boundaries	- Coastal boundaries and inland water bodies (NGDC)

- Coefficients for surface roughness, and relations between vegetation indices and vegetation opacity, are derived from field experiments at L-band for a variety of conditions
  - These coefficients are expected to be relatively time-invariant at satellite footprint spatial scales (~40 km)
  - They can be fine-tuned during the post-launch calibration/validation phase.

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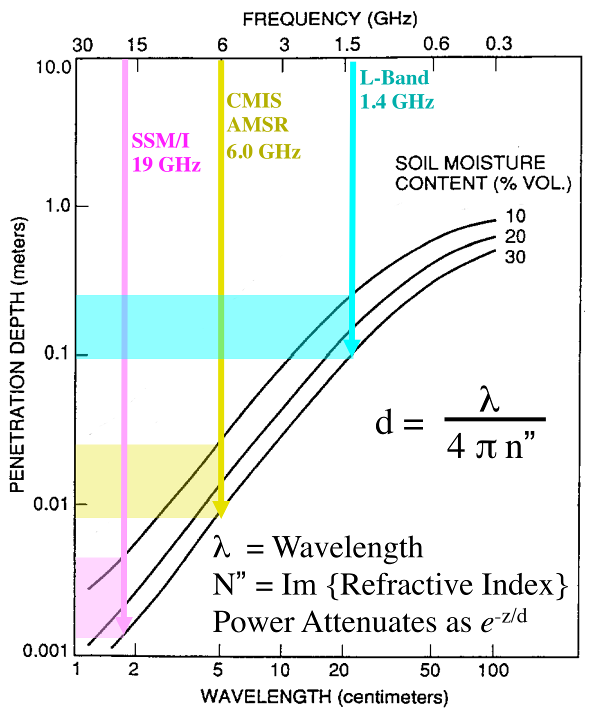
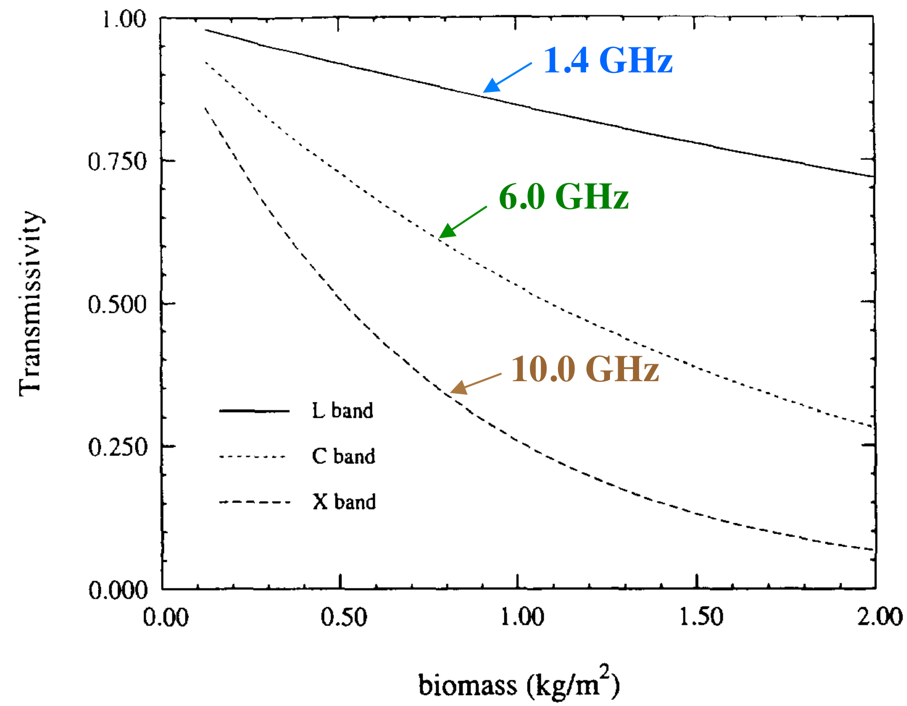
Advantages of Sensing at L-Band



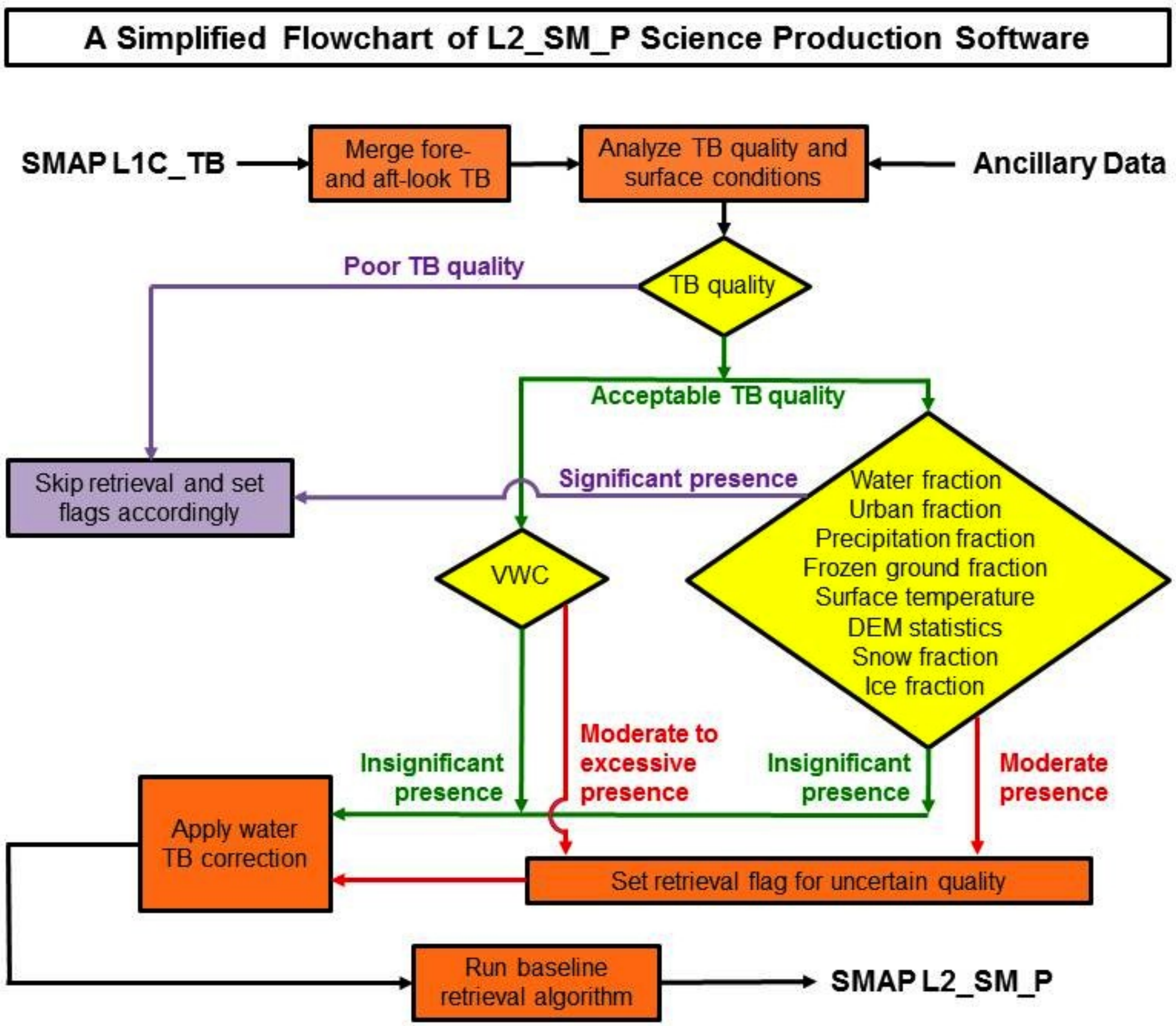
Effective sensing depth decreases with increasing measurement frequency



Vegetation attenuation increases with increasing measurement frequency

L-band provides significant improvements in soil moisture sensing capability over previous missions (e.g. AMSR-E at C-band)

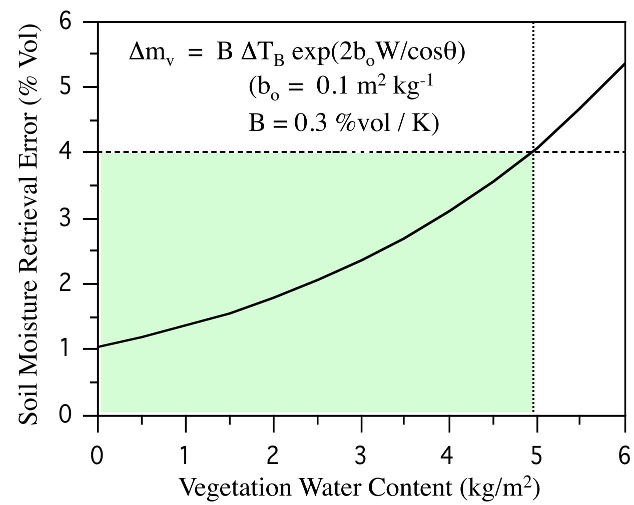
L2_SM_P Product Generation Flow Chart



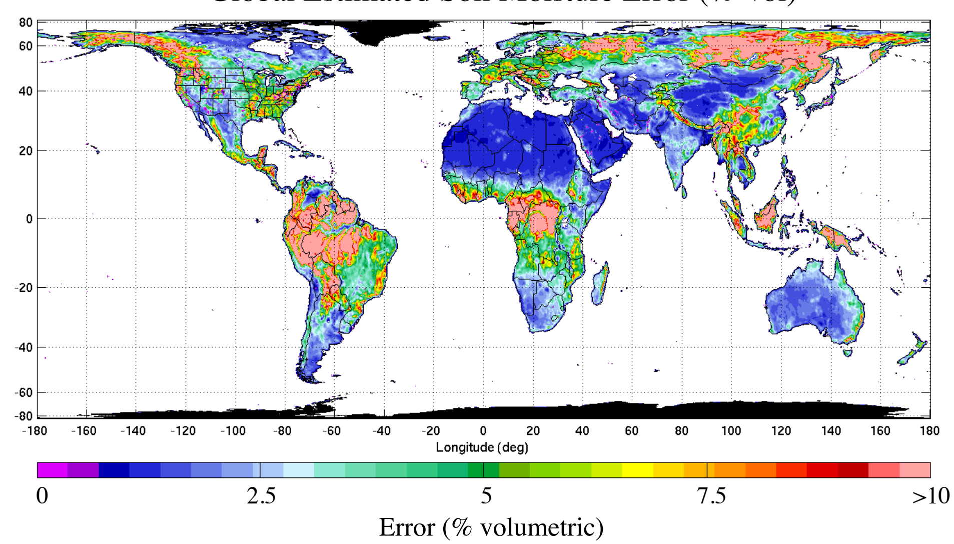
Error Budget and Global Retrieval

Error Source	Estimated T_B Error (K)	
	Expected	**Budget**
Faraday Rotation	0.15	0.2
Atmospheric Gasaes & Clouds	0.1	0.15
Surface Temperature	1.4	1.7
Vegetation Water Content	1.2	1.6
Model Parameterization	1.1	1.4
Landscape Heterogeneity	0.8	1.0
RSS of Geophysical Errors	**2.3**	**2.9**
Sensor Relative Error (Precision and Calibration Stability)	0.9	1.5
Total RSS Error (ΔT_B)	**2.5**	**3.3**

Soil Moisture Retrieval Error vs. VWC



Global Estimated Soil Moisture Error (% Vol)



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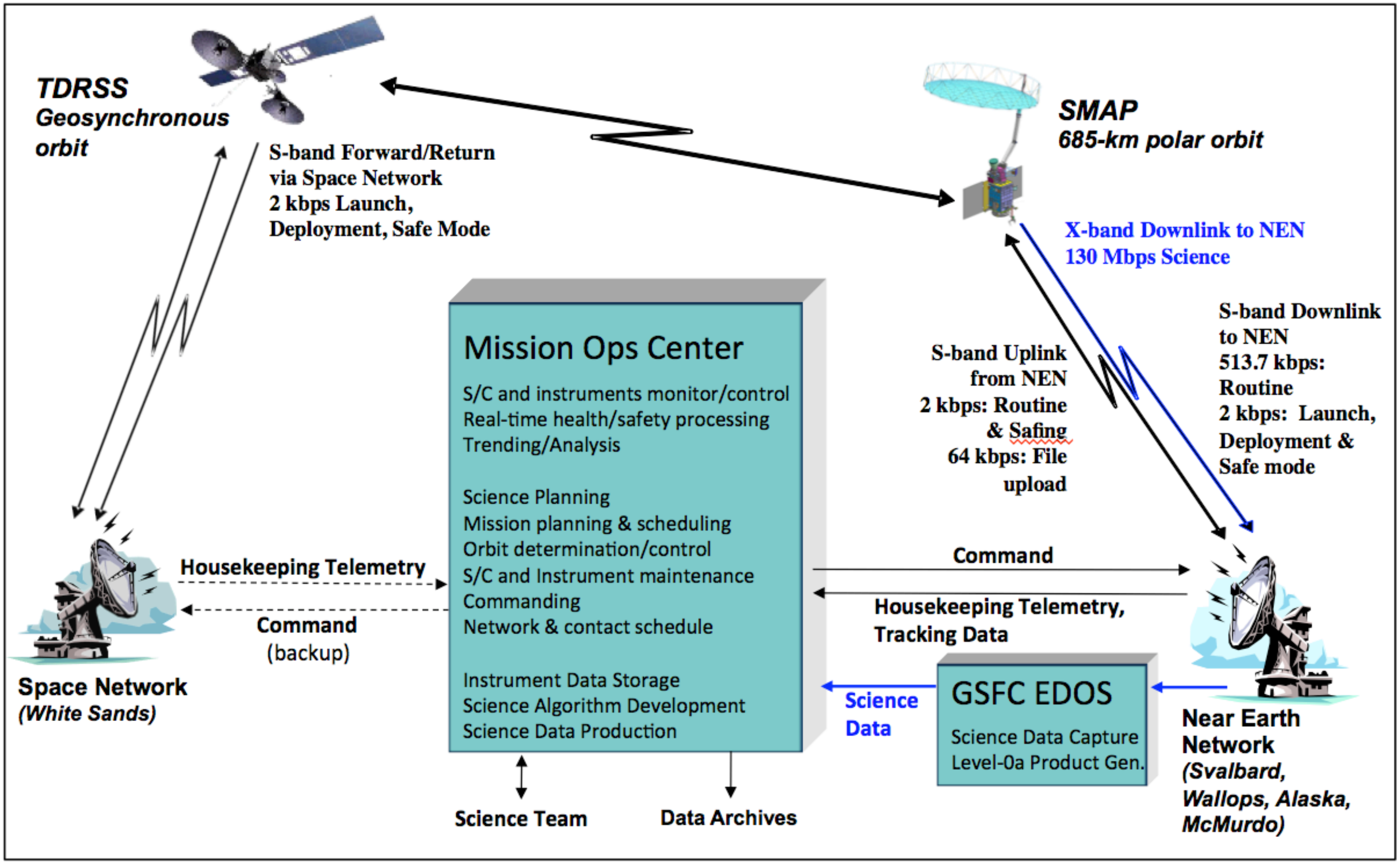
Mission Operations

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SMAP Data Products

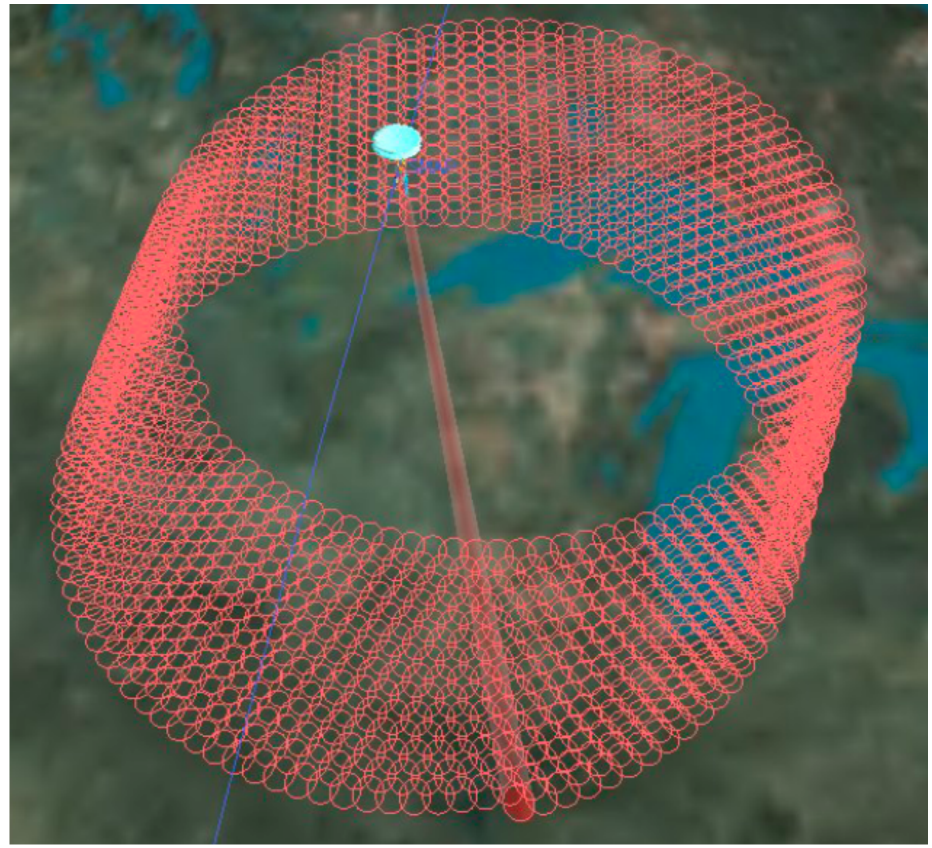
Data Product Short Name	Description	Grid Resolution	Granule Extent
L1A_Radar	Parsed Radar Instrument Telemetry		Half Orbit
L1A_Radiometer	Parsed Radiometer Instrument Telemetry		Half Orbit
L1B_S0_LoRes	Low Resolution Radar σ_o in Time Order	5x30 km (10 slices)	Half Orbit
L1C_S0_HiRes	High Resolution Radar σ_o on Swath Grid	1 km	Half Orbit
L1B_TB	Radiometer T_B in Time Order	39x47 km	Half Orbit
L1C_TB	Radiometer T_B	36 km	Half Orbit
L2_SM_A	Radar Soil Moisture (includes Freeze-Thaw)	3 km	Half Orbit
L2_SM_P	Radiometer Soil Moisture	36 km	Half Orbit
L2_SM_AP	Active-Passive Soil Moisture	9 km	Half Orbit
L3_FT_A	Daily Global Composite Freeze/Thaw State	3 km	North of 45° N
L3_SM_A	Daily Global Composite Radar Soil Moisture	3 km	Global
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	36 km	Global
L3_SM_AP	Daily Global Composite Active-Passive Soil Moisture	9 km	Global
L4_SM	Surface & Root Zone Soil Moisture	9 km	Global
L4_C	Carbon Net Ecosystem Exchange	9 km	North of 45° N

SMAP Data Product Availability

Data Product Short Name	Description	Initial Availability After Commissioning	Latency to User Community after Acquisition
L1A_Radar	Parsed Radar Instrument Telemetry	3 months	12 hours
L1A_Radiometer	Parsed Radiometer Instrument Telemetry	3 months	12 hours
L1B_S0_LoRes	Low Resolution Radar σ_o in Time Order	3 months	12 hours
L1C_S0_HiRes	High Resolution Radar σ_o on Swath Grid	3 months	12 hours
L1B_TB	Radiometer T_B in Time Order	3 months	12 hours
L1C_TB	Radiometer T_B	3 months	12 hours
L2_SM_A	Radar Soil Moisture	3 months	24 hours
L2_SM_P	Radiometer Soil Moisture	3 months	24 hours
L2_SM_AP	Active-Passive Soil Moisture	3 months	24 hours
L3_FT_A	Daily Global Composite Freeze/Thaw State	6 months	50 hours
L3_SM_A	Daily Global Composite Radar Soil Moisture	6 months	50 hours
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	6 months	50 hours
L3_SM_AP	Daily Global Composite Active-Passive Soil Moisture	6 months	50 hours
L4_SM	Surface & Root Zone Soil Moisture	6 months	7 days
L4_C	Carbon Net Ecosystem Exchange	6 months	14 days

Data Acquisition Plan

- Radiometer data:
  - Continuous collection over the entire orbit and entire 360 degree antenna scan
- Synthetic Aperture Radar (SAR) data:
  - Collection over the entire 360 degree antenna scan over land and coastal water during the AM orbit
  - Collection over the forward portion of the antenna scan over land and coastal water North of 45 degrees North latitude during the PM orbit.
- Low-resolution, real aperture radar data
  - Continuous collection over entire orbit and entire antenna scan



SMAP Data Product Design

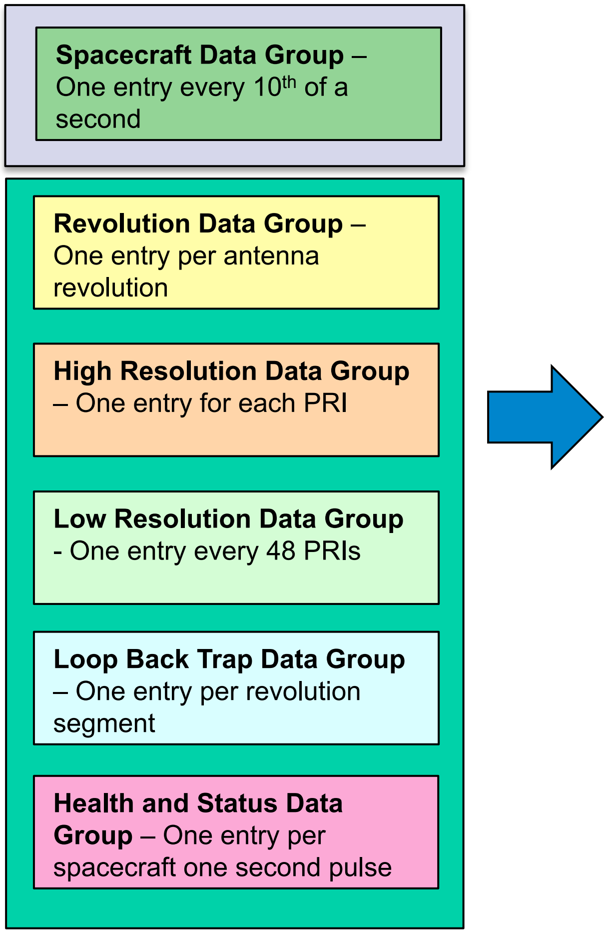
- **All products are in HDF format**

- Each SMAP HDF file contains the primary data file (e.g. soil moisture, freeze/thaw, radar data) and all files used in the production of that primary dataset. These files include metadata, instrument data, flags and masks, data product, etc.

- **Projection: EASE2 grid**
  - Equal area projection
  - Level 2, 3, 4, and radiometer L1C are in this projection

- **Values**
  - Radiometer data (brightness temperature) is in Kelvin)
  - Radar data is in sigma naught
  - Soil moisture is a volumetric measurement expressed as cm^3/cm^3
  - Freeze/thaw is a binary measurement, either frozen or thawed

Radar Level 1A Product



- Spacecraft Data Group
  - Includes records of spacecraft position and attitude every 10th of a second
- Revolution Data Group
  - Includes begin time for each antenna scan, pri length and segment frequencies
- High Resolution Data Group
  - Includes high resolution acquisition time, and HH, VV and either HV or VH high resolution data using Block Floating Point Quantizer (BFPQ) mantissas and exponents.
- Low Resolution Data Group
  - Includes low resolution acquisition time, low resolution data for all four channels, loop back and noise only data for all four channels.
- Loop Back Trap Data Group
  - Includes loop back trap acquisition time, look back trap data for all four channels
- Health and Status Data Group
  - Includes correlation between spacecraft time and radar instrument time, voltage and temperature sensor readings as telemetry data numbers (DN) and Engineering Units (EU)

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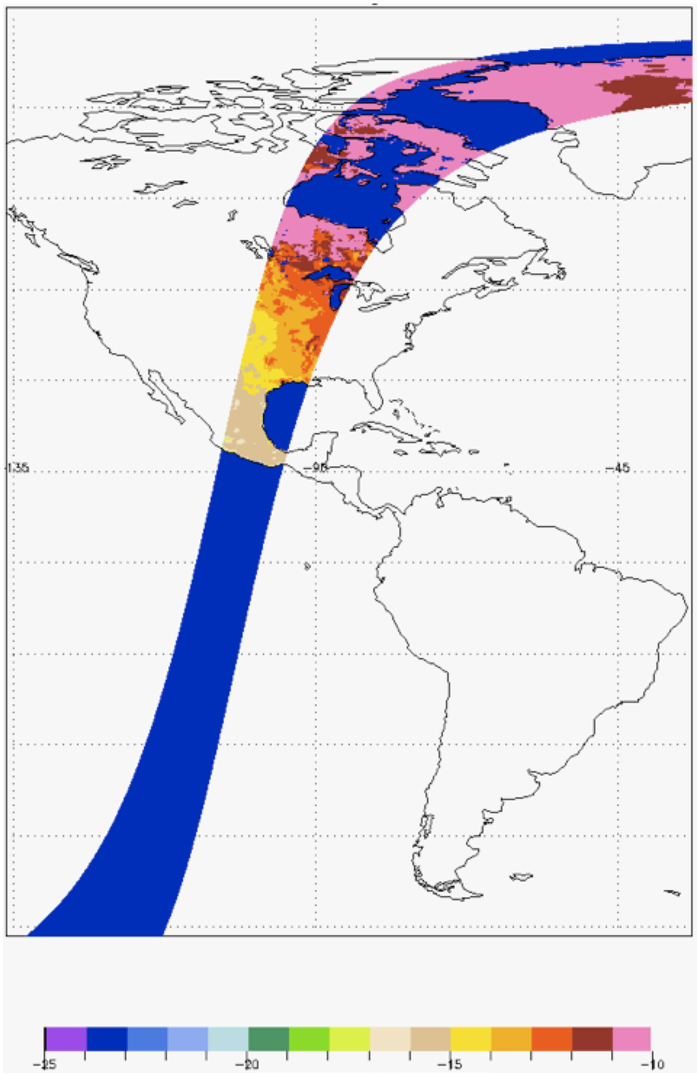
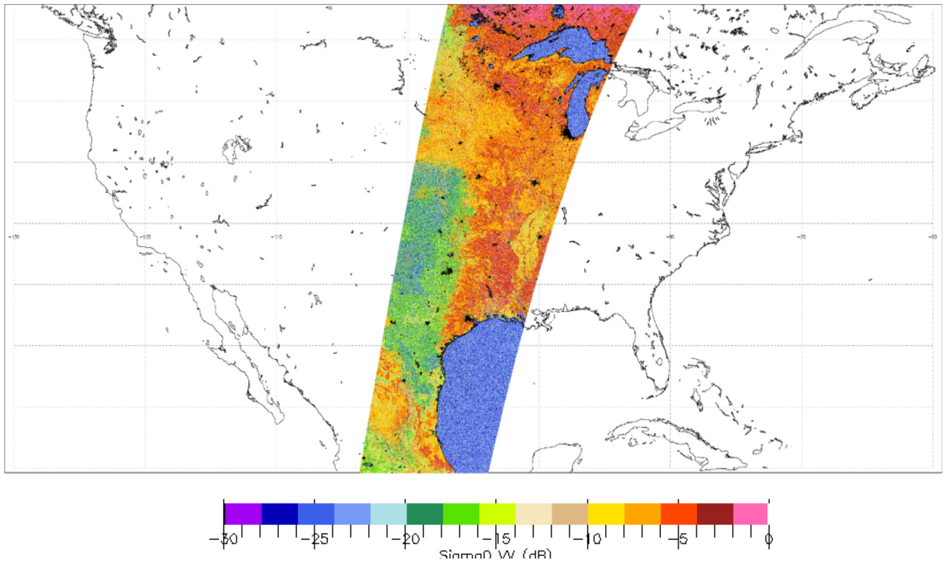
Radar Level 1B Product



Sigma0 VV (dB)

- Each granule contains time ordered data that covers one spacecraft half orbit.
- Coverage is continuous over all surface types.
- Contains Earth-located, calibrated radar backscatter measurements for co-pol and cross-pol data.
- Estimated Kp errors assigned to each measurement.
- Includes spacecraft orbit and attitude information and instrument pointing geometry.
- Includes short term and external calibration data used to generate product output.
- Provides calibrated backscatter measurements for approximately ten range-resolved "slices" of the full radar FOV footprint. (~30 km by 5 km.)

Radar Level 1C Product



Sigma0 VV (dB)

- Each granule contains geographically ordered data in 1 km grid cells in an along track/cross track swath grid.
- Coverage is restricted to land and coastal water over one spacecraft half orbit.
- SAR provides high-resolution single-look measurements. Resolution varies from ~400 m at the swath edge to about 1.2 km at 150 km from the nadir sub-track. Nadir looks are thin slices as wide as the beam footprint.

- Contains Earth located and calibrated h-pol, v-pol and cross-pol backscatter measurements, each separately multilooked
- Radar measurements achieve 1 km resolution over 70% of the swath. Resolution degrades in the nadir region.
- Forward looking and aft looking measurements stored separately.
- Includes spacecraft orbit and attitude information and instrument pointing geometry.
- Includes short term and external calibration data used to generate product output.
- Provides reference to global and polar 1 km EASE grid coordinates.

Radiometer Level 1A Product

Spacecraft Data – One entry per antenna revolution

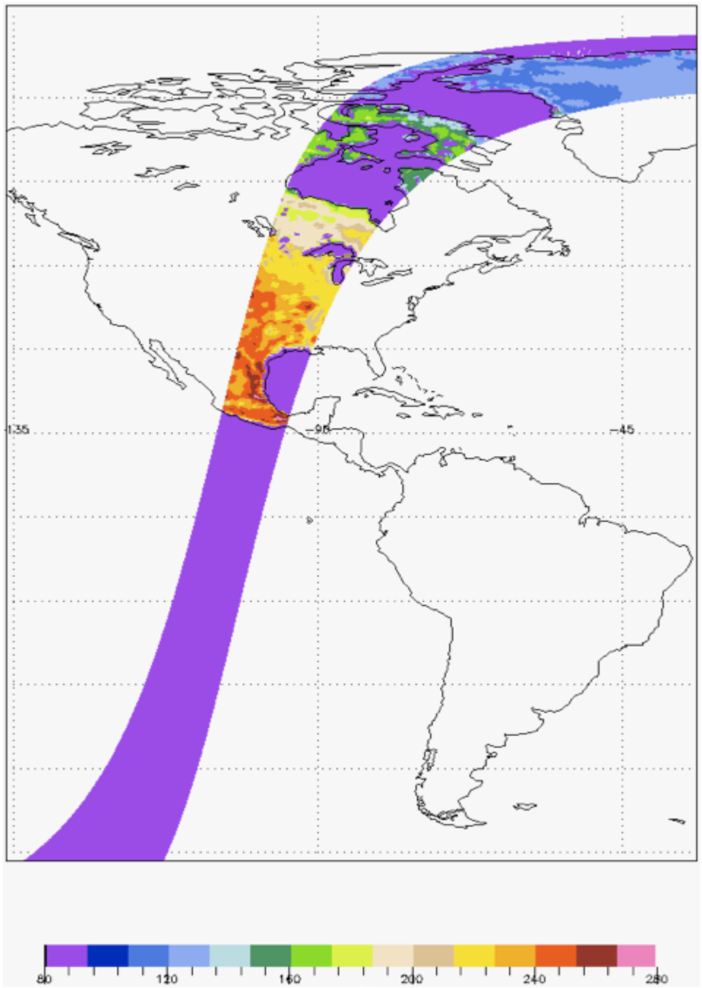
Subband Moments Data – One entry per packet (every 4 PRIs) over land

Fullband Moments Data – One entry per PRI

House Keeping Group –
status_dn
digital_dn
analog_dn
analog_eu

- Spacecraft data
  - Includes antenna scan times, S/C lat, lon, alt, vel, position, roll, pitch, yaw and rotation rate
- Subband Moments Data
  - Data obtained for 16 subbands
  - V and H polarization
  - Moments 1-4
  - 5 radiometric states: antenna, antenna + external noise diode, antenna + internal noise diode, reference, reference + internal noise diode
  - Occurs once very 4 PRIs
- Fullband Moments Data
  - V and H polarization
  - Moments 1-4
  - 5 radiometric states: antenna, antenna + external noise diode, antenna + internal noise diode, reference, reference + internal noise diode
  - Occurs every PRI
- House Keeping Group
  - Contains status and digital information from engineering telemetry
  - Analog digital numbers for temperatures and voltages
  - Analog engineering units for temperatures and voltages
  - Engineering telemetry obtained once per scan

Radiometer Level 1B Product



L1B Time-ordered H-pol TB (K)

- Each granule contains time ordered data that covers one spacecraft half orbit.
- Effective field of view footprint is a 39 km by 47 km ellipse
- Earth-located calibrated data for each EFOV
  - Apparent aperture (antenna) temperatures
  - Top-of-ionosphere (TOI) brightness temperature
  - Surface-referenced brightness temperatures
- Coverage continuous over all surface types.
- All four modified Stokes parameters (V, H, 3 & 4).
- 3rd Stokes used for Faraday rotation correction.
- Time-frequency-polarization diversity used for RFI detection and removal.
- Forward looking and aft looking measurements stored separately.
- Includes spacecraft orbit and attitude information and instrument pointing geometry.

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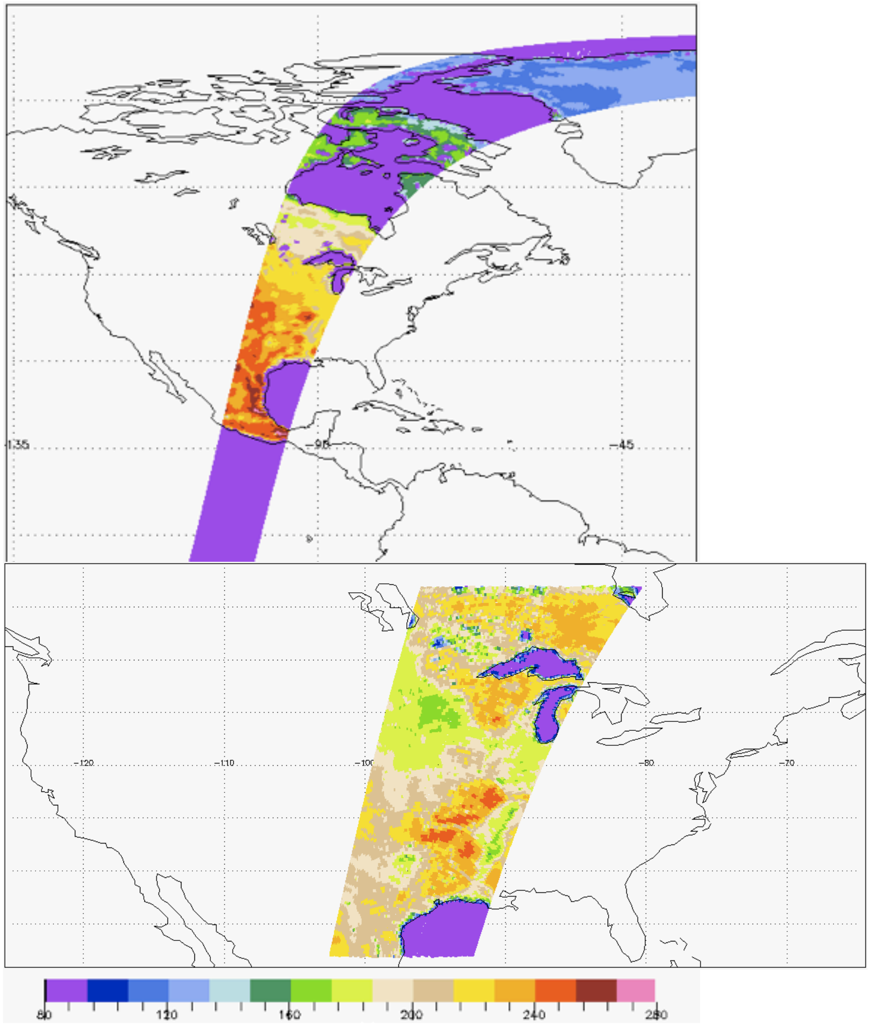
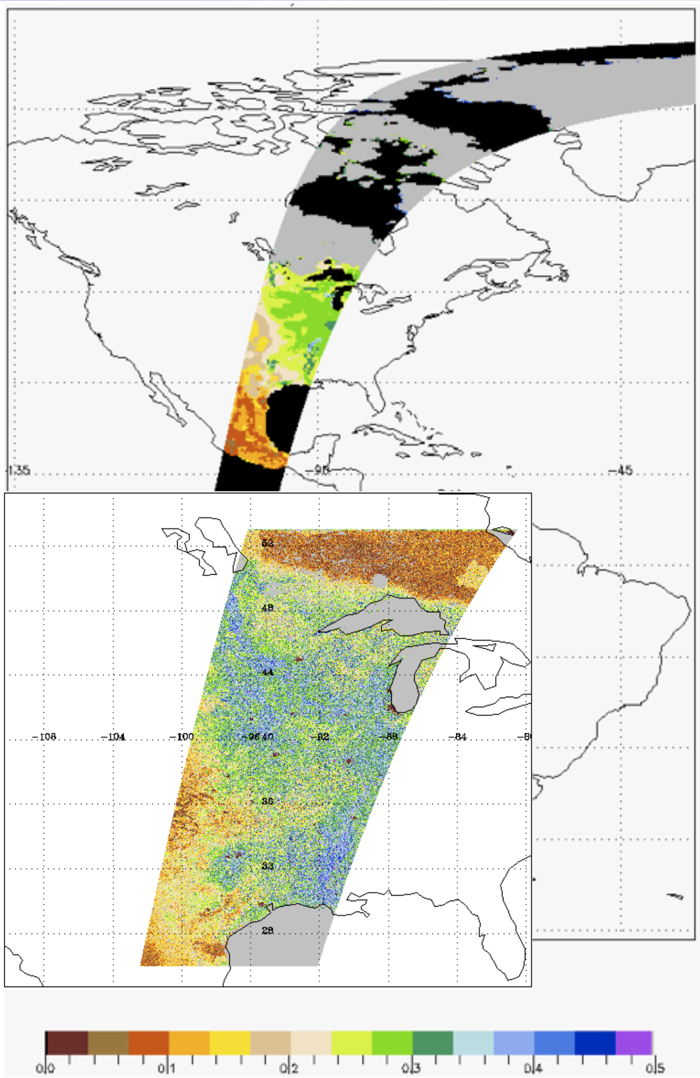
Radiometer Level 1C Product



L1C Earth-fixed H-pol TB (K)

- Each granule represents one spacecraft half orbit.
- Contains Level 1B Radiometer data represented on a cylindrical 36 km EASE grid and two polar 36 km EASE grids.
- Data are represented in a one dimensional array.
- Product lists only those EASE grid cells that contain data.
- Latitude and longitude listed for each EASE grid cell.
- Forward looking and aft looking observations stored separately.
- Input to Level 2 Radiometer 40 km soil moisture and Level 2 active/ passive soil moisture processing.

Level 2 High Resolution Radar 3 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Each granule contains one half orbit of data posted on 3 km cylindrical EASE grid cells.
- Data are represented in a one dimensional array.
- Product lists only those EASE grid cells that contain data.
- AM Product covers entire Earth land mass, PM product restricted to land north of 45 North longitude
- PM data acquired specifically for freeze-thaw retrievals.
- Employs 1 km high resolution radar L1C data averaged over 3 km cylindrical EASE grid cells to reduce Kp noise.
- Soil moisture retrievals use snapshot and/or time-series algorithms.
- Depending on the terrain classification, multiple optional models/algorithms may be employed for retrieval.
- **Provides freeze-thaw state and transient water body information that the other Level 2 soil moisture processes require.**
- Includes quality masks for urban areas, mountainous terrain, dense vegetation, snow and ice.

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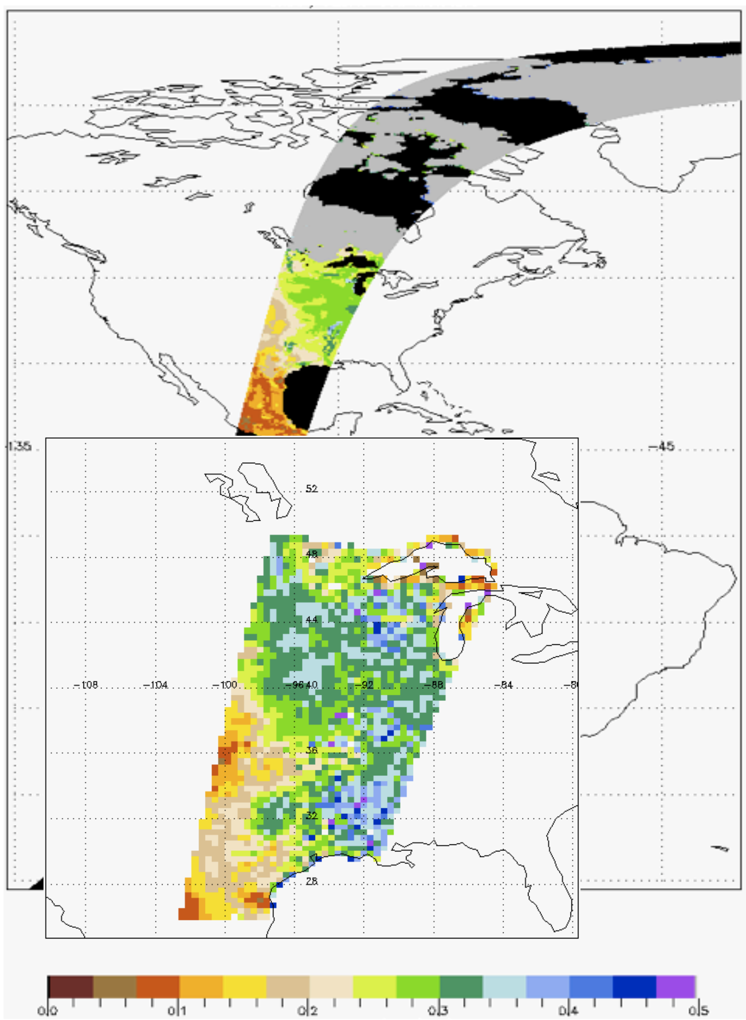
Level 2 Radiometer 36 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Each granule contains one half orbit of data posted on 36 km cylindrical EASE grid cells.
- Data are represented in a one dimensional array.
- Product lists only those EASE grid cells that contain data.
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas.
  - Low to moderate vegetation defined as vegetation water content <= 5 kg/m^2.
- Requires transient water body and freeze-thaw state retrievals generated with high resolution radar retrievals.
- Estimates soil moisture based on AM observations.
- Includes quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice.

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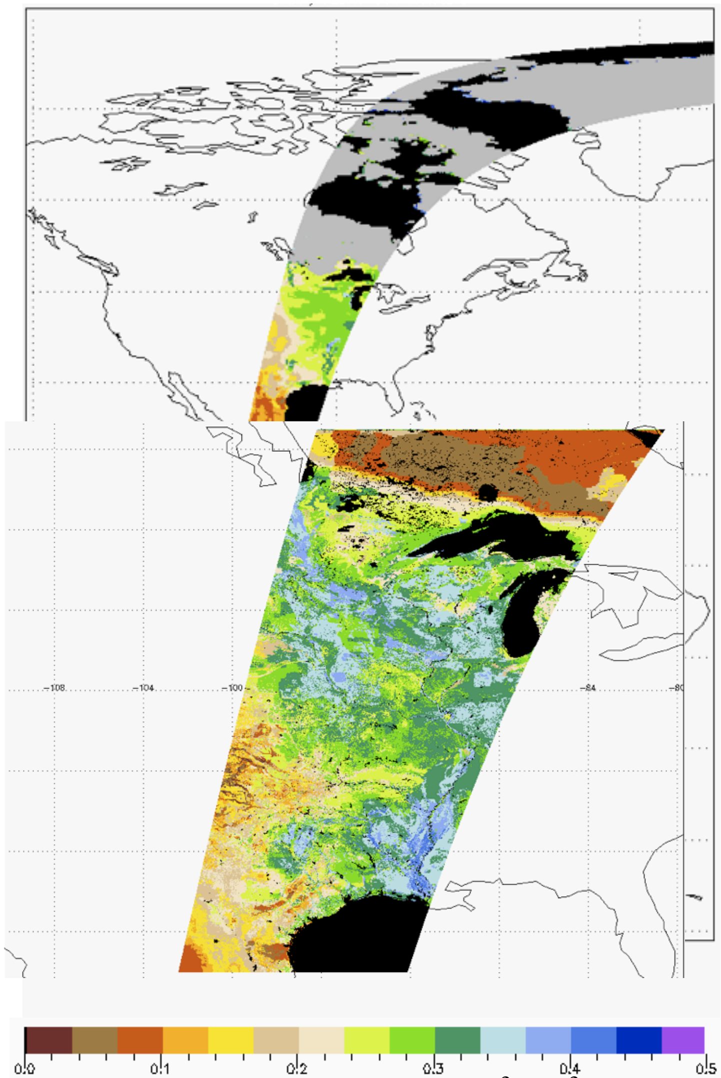
Level 2 Active/Passive 9 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Each granule contains one half orbit of data posted on 9 km cylindrical EASE grid cells.
- Data are represented in a one dimensional array.
- Product lists only those EASE grid cells that contain data.
- Merges radar and radiometer channels using a time series algorithm and spatial heterogeneity of L1C radar product.
- Provides dis-aggregated brightness temperatures at 9 km resolution.
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas.
  - Low to moderate vegetation defined as vegetation water content <= 5 kg/m^2.
- Employs transient water body and freeze-thaw state generated with high resolution radar retrievals.
- Include quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice.

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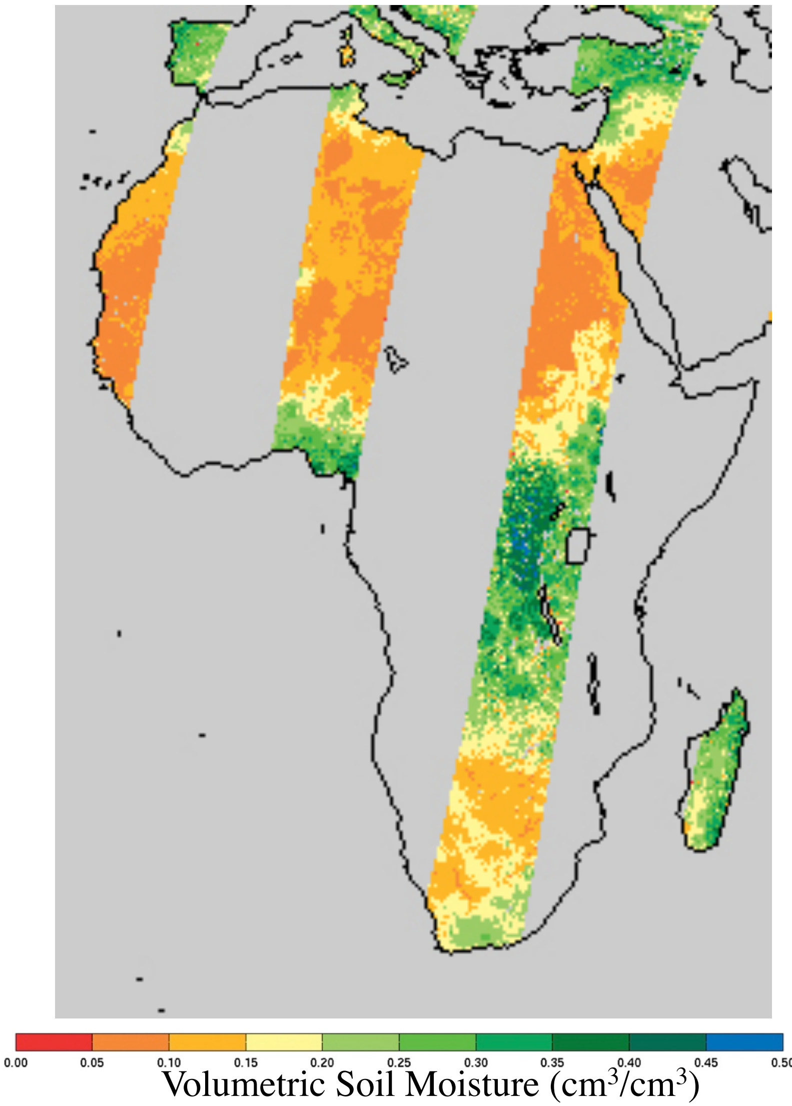
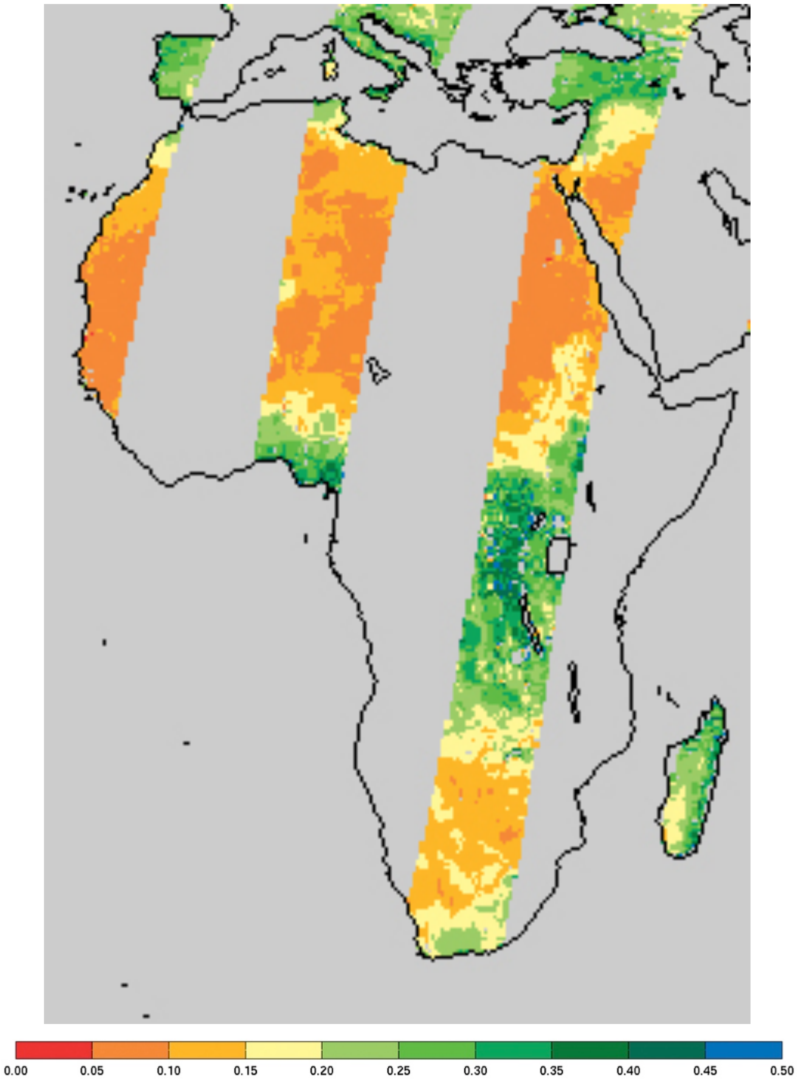
Level 3 High Resolution Radar 3 km Soil Moisture Product



- Composite of all Radar Level 2 half orbit products where the local acquisition time is the same UTC day.
- Multiple measurements may overlap at high latitudes. Algorithm selects those measurements acquired closest to 6 AM solar time.
- Posted on a 3 km cylindrical EASE grid using a two dimensional array.
- Product lists all EASE grid cells, regardless of whether data are available.
- Soil moisture retrievals use snapshot and/or time-series algorithms.
- Depending on the terrain classification, multiple optional models/algorithms may be employed for retrieval.
- Based exclusively on AM data.

Level 3 Radiometer 36 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Composite of all Radiometer Level 2 half orbit products where local acquisition time is the same UTC day.
- Multiple measurements may overlap at high latitudes. Algorithm selects measurements acquired closest to 6 AM solar time.
- Posted on a 36 km cylindrical EASE grid using a two dimensional array.
- Product lists all EASE grid cells, regardless of whether data are available.
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas.
  - Low to moderate vegetation defined as vegetation water content <= 5 kg/m^2.
- Based exclusively on AM data.

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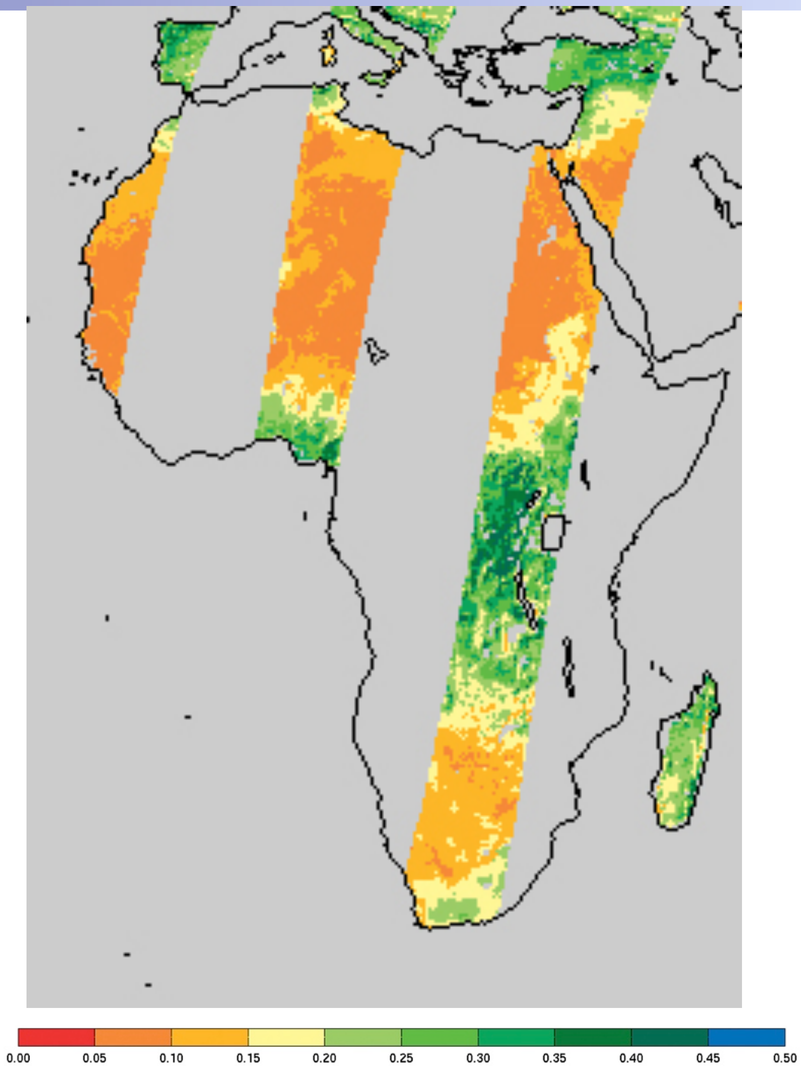
Level 3 Active/Passive 9 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Composite of all Active/Passive Level 2 half orbit products where local acquisition time is the same UTC day.
- Multiple measurements may overlap at high latitudes. Algorithm selects measurements acquired closest to 6 AM solar time.
- Posted on a 9 km cylindrical EASE grid using a two dimensional array.
- Product lists all EASE grid cells, regardless of whether data are available
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas.
  - Low to moderate vegetation defined as vegetation water content <= 5 kg/m^2.
- Based exclusively on AM data.

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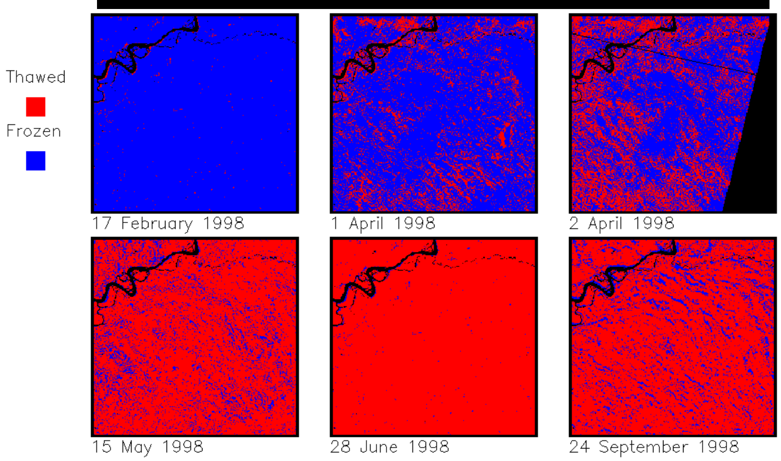
Level 3 Freeze/Thaw Product



Daily Freeze/Thaw State

- Employs the 1 km Level 1C high resolution radar data and a time-series change detection algorithm to infer freeze/thaw state.
- Quantifies daily freeze/thaw state as a binary condition for land surface.
- Includes both AM and PM data, with intra-day state transition flags.
- Posted on a 3 km polar EASE grid with 3 km spatial resolution using a two dimensional array.
- Each product represents a single calendar day UTC.
- Required to achieve 80% freeze/thaw state classification accuracy.

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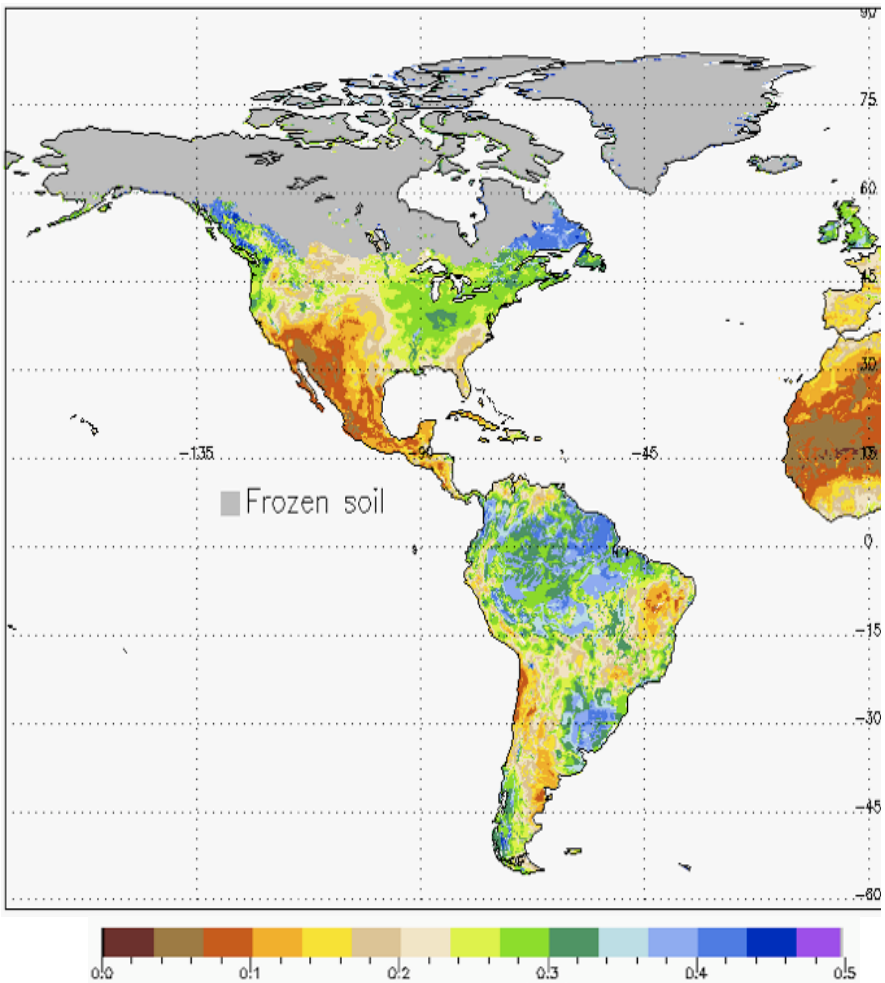
Level 4 Surface and Root-Zone Soil Moisture Product

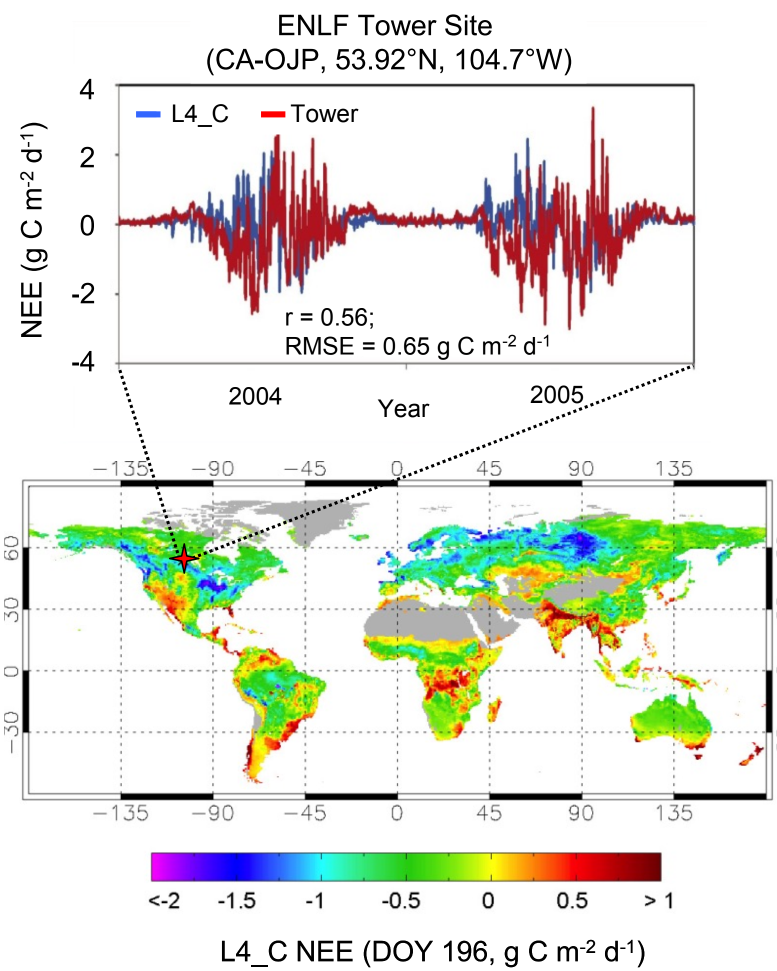


Volumetric Soil Moisture (%)

- Global output represents 3 hour intervals at 9 km resolution with 7-day latency.
- Product subdivides
  - Instantaneous measures once every 3 hours
  - Time averaged values over a three hour time span.
- Employs SMAP L1C Radiometer, Level 2 AP Disaggregated Brightness Temperatures as well as Level 3 Freeze/Thaw products.
- Assimilates SMAP data into a state-of-the-art land surface model to derive global estimates of root-zone moisture.
- Root zone soil moisture- 1 meter deep

Level 4 Carbon Product

Mean Daily net CO_2 Exchange



- Daily global maps of net ecosystem CO_2 exchange (NEE) at 9 km resolution with 14-day latency.
- Quantifies the net carbon flux in boreal landscapes.
- Reduces uncertainty with regard to existing carbon sinks on land.
- Applies a soil decomposition algorithm driven by SMAP L4_SM and Gross Primary Production (GPP) inputs to compute net land-atmosphere CO_2 exchange (NEE).
- Accuracy commensurate with tower based CO_2 observations. (RMSE $\leq$ 30 g C m^{-2} yr^{-1} or 1.6 g C m^{-2} d^{-1}).

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Regions of Soil Moisture and Freeze/Thaw Retrievals

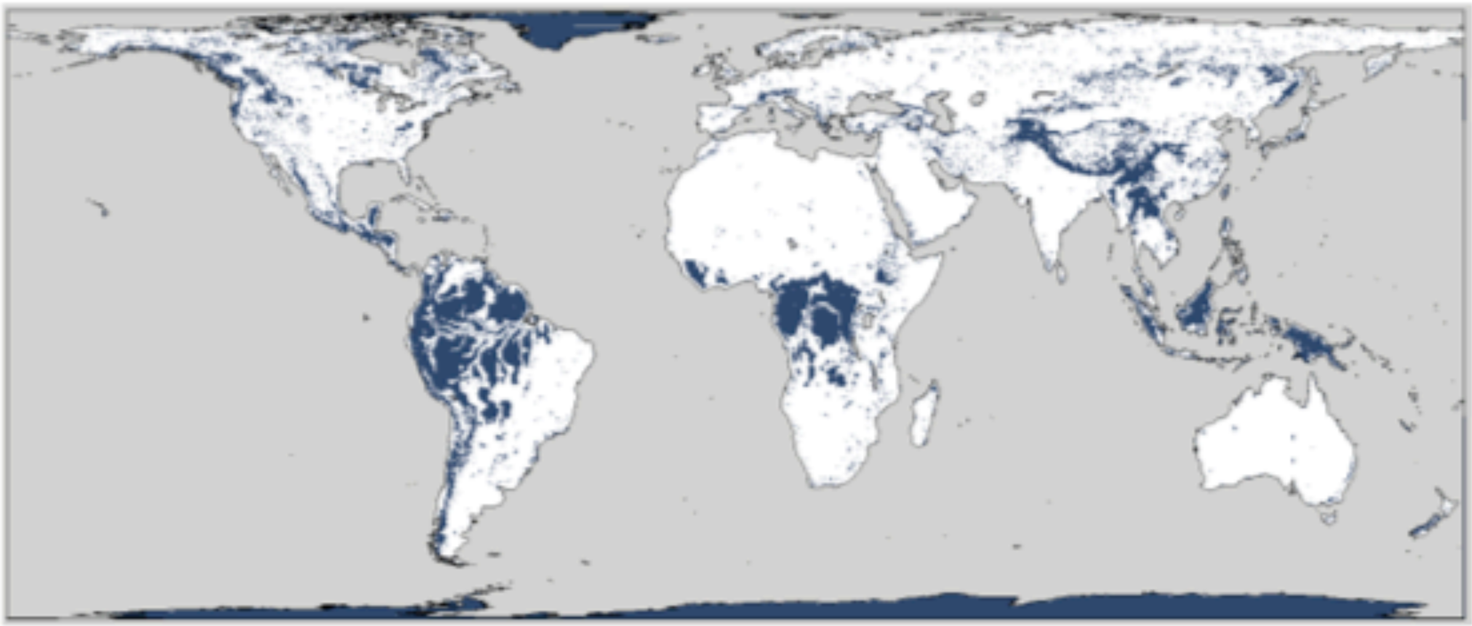


Figure 2-1. Regions of coverage (white areas) where soil moisture requirements are to be met.

Urban areas, complex topography, permanent snow and ice, and areas where vegetation water content is >5 kg/m^2 have been excluded.

Figure 2-2. Regions of coverage (white areas) where freeze/thaw requirements are to be met.

Availability of Validated Data Products

- The initial product delivery to the public will be three months after instrument commissioning, six months after launch. **These will be beta version products**.
  - Initial **validated** Level 1 products appear six months after instrument commissioning, or about nine months after launch.
  - Initial **validated** Level 2, Level 3 and Level 4 products appear twelve months after instrument commissioning, or about fifteen months after launch.

Data Maturity Levels

BetaProducts intended to enable users to gain familiarity with the parameters and the data formats.

ProvisionalProduct was defined to facilitate data exploration and process studies that do not require rigorous validation. These data are partially validated and improvements are continuing; quality may not be optimal since validation and quality assurance are ongoing.

ValidatedProducts are high quality data that have been fully validated and quality checked, and that are deemed suitable for systematic studies such as climate change, as well as for shorter term, process studies. These are publication quality data with well-defined uncertainties, but they are also subject to continuing validation, quality assurance, and further improvements in subsequent versions. Users are expected to be familiar with quality summaries of all data before publication of results; when in doubt, contact the appropriate instrument team.

- **Stage 1 Validation**: Product accuracy is estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts.
- **Stage 2 Validation**: Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.
- **Stage 3 Validation**: Product accuracy has been assessed. Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
- **Stage 4 Validation**: Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.

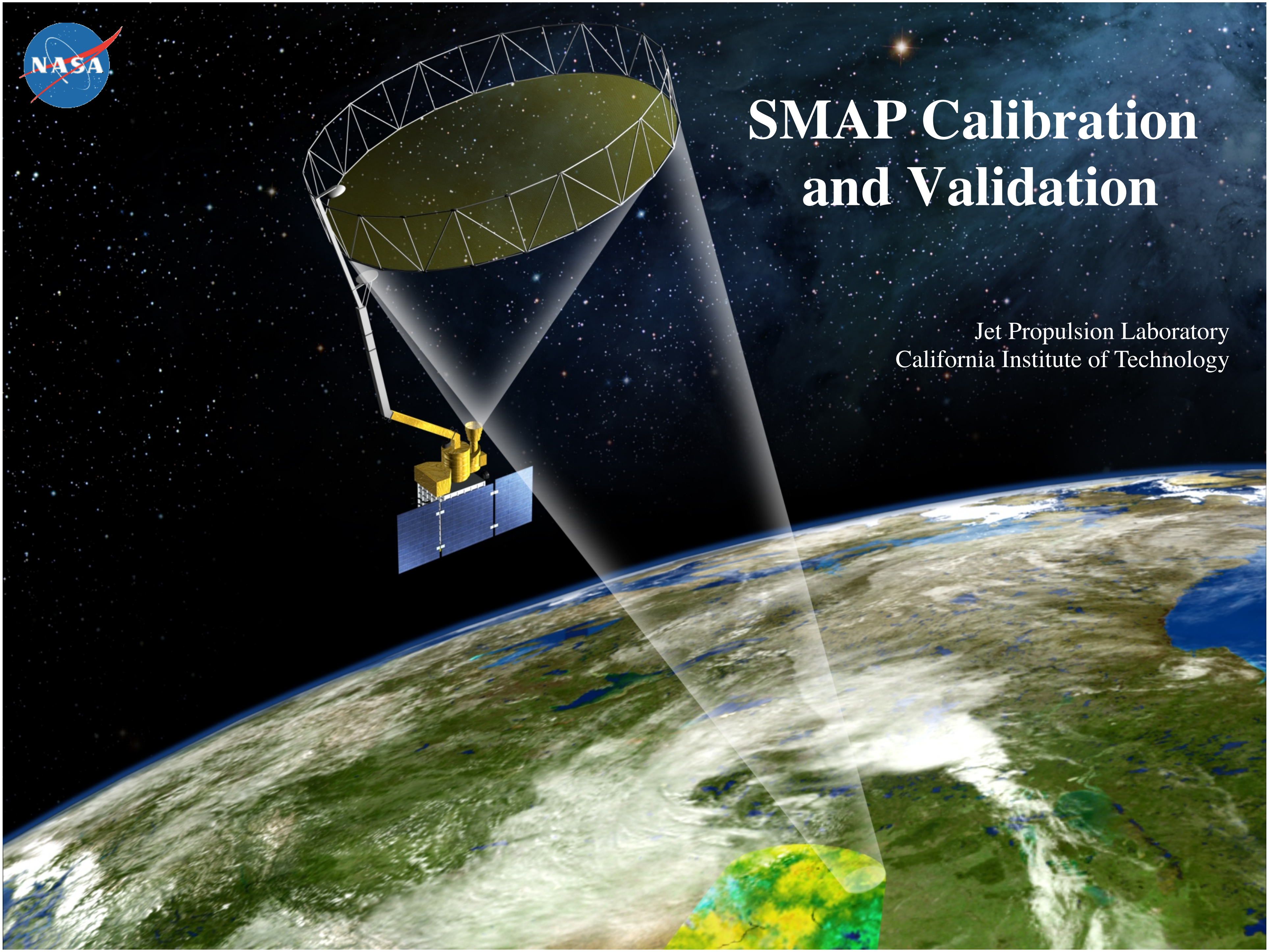
Extracted from http://science.nasa.gov/earth-science/earth-science-data/data-maturity-levels/

SMAP Data Access

SMAP data products will be **freely** available through the National Snow and Ice Data Center (NSIDC) and Alaska Satellite Facility (ASF)

- http://nsidc.org/data/smap (for all SMAP L2, L3, and L4 products and L1A, L1B, and L1C radiometer data)

- https://www.asf.alaska.edu/smap/data-imagery/ (for all SMAP L1 radar data- L1A_Radar, L1B_SO_LoRes, and L1C_S0_HiRes)



SMAP Calibration and Validation

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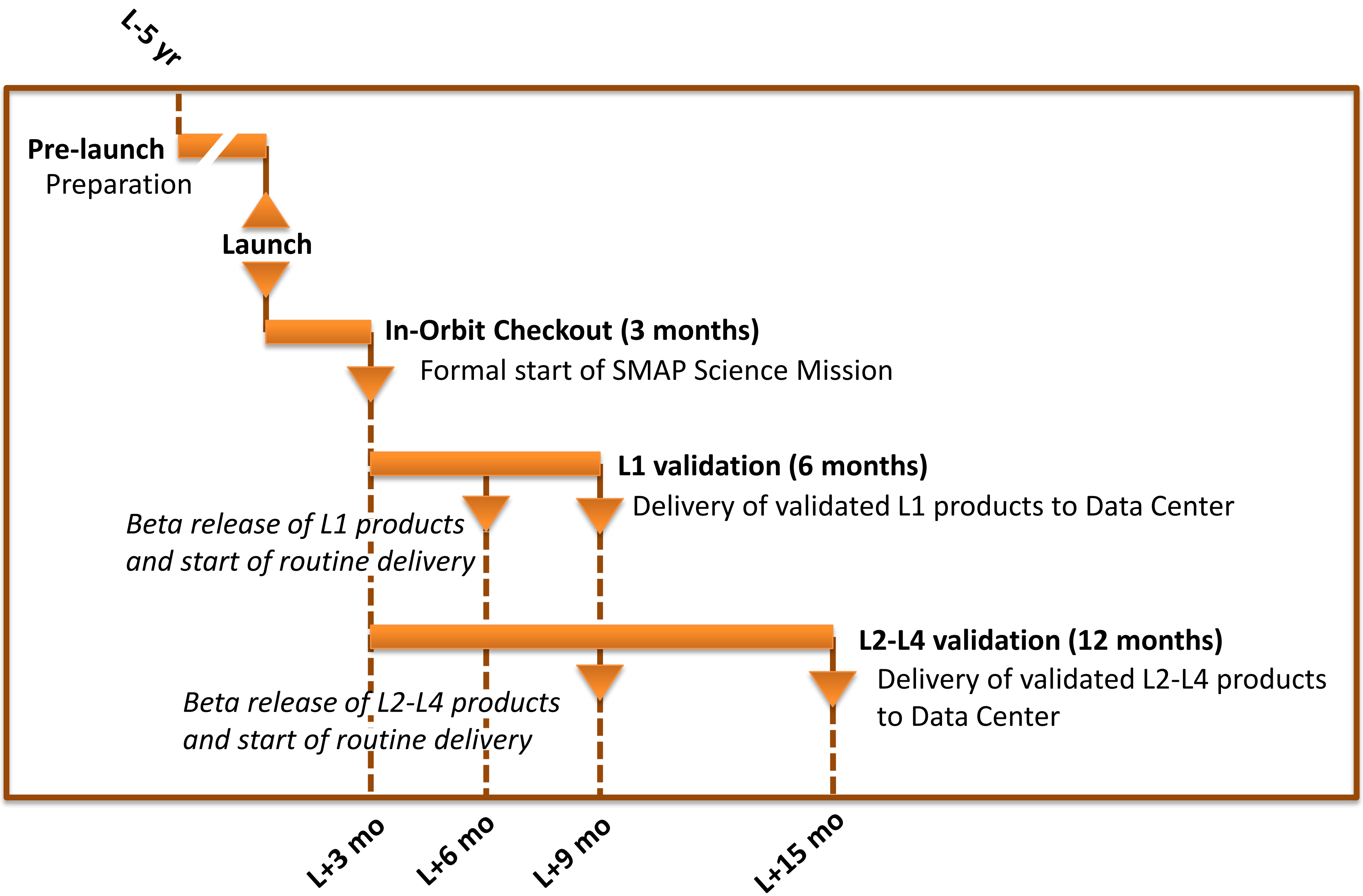
SMAP Cal/Val Timeline



Cal/Val Methodologies

Methodology	Role	Analysis tools and readiness
Core Validation Sites	Accurate estimates of products at matching scales for a set of conditions with spatially distributed in situ sensors	✓ Data transfer from Cal/Val Partners set up and/or automated ✓ Scaling methods defined ✓ Offset grid processing
Sparse Networks	One point in the grid cell for a wide range of conditions	✓ Triple collocation method tool completed ✓ Data transfer from Cal/Val Partners automated
Satellite Products	Estimates over a very wide range of conditions at matching scales	✓ Cross comparison tools developed for SMOS, GCOM-W and Aquarius ✓ Task Group formed
Model Products	Estimates over a very wide range of conditions at matching scales	✓ Developed high-res 3 and 9 km model products ✓ Statistical comparison methods developed
Field Campaigns	Detailed assessment of the scaling issues for a set of high priority conditions	✓ SMAPVEx15 and 16 campaigns defined ✓ Australia campaign planned in 2015

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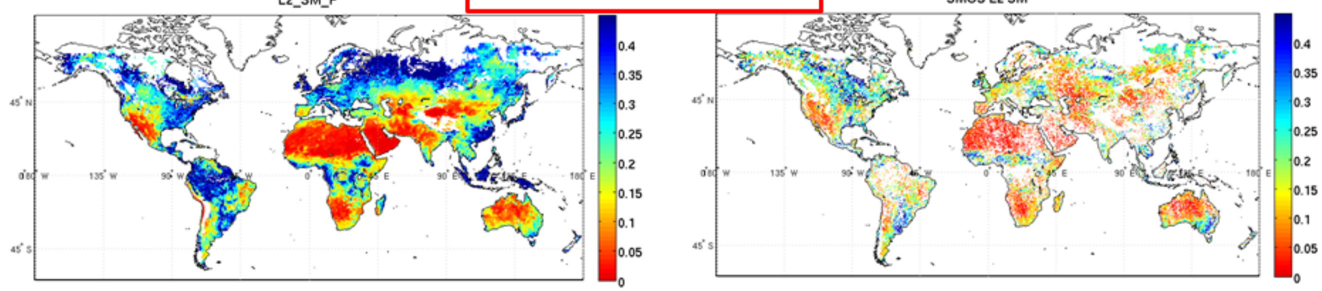
Satellite Soil Moisture Data Characteristics

	Mission Duration	SM Spatial Coverage[1]	SM Product Resolution/ Grid (km)	Temporal Revisit	Orbit	Data Latency
SMOS	2009-?	Global land	P L2 (40) P L4 (9)	~3 days	Sun-synch (6am asc / 6pm desc)	?
Aquarius	2011-?	Global land	P L3 (1deg)	?	Sun-synch (6pm asc / 6 am desc)	?
GCOM-W/ AMSR2	2013-?	Global land	JAXA (25) NPD/SCA (25) LPRM (?)	?	(1:30 pm asc / 1:30 am desc)	?
SMAP	2015-2018	Global land	P[2] (40/36) AP[2] (9) A[2] (3)	~3 days	Sun-synch (6am desc / 6pm asc)	?
SAOCOM	2016-2021 2017-2022	Argentina Pampas	?	?	?	?
ASCAT	?	Global land	MetOP (12.5/25) WACMOS ?	?	Sun synch (9:30pm asc / 9:30am desc)	?
WindSat ?	2004-?	?	?	?	Sun synch	?

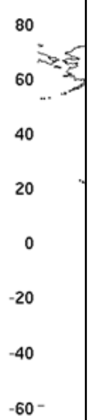
[1] Except RFI, mountains, urban, snow, frozen, dense vegetation, water, etc.
[2] Baseline and options

Soil Moisture Satellite Product Comparisons: Simulated SMAP SM vs. SMOS SM

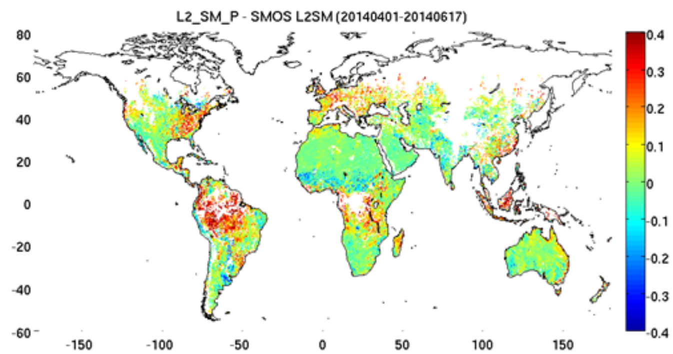
2014/05/30 - 2014/06/02

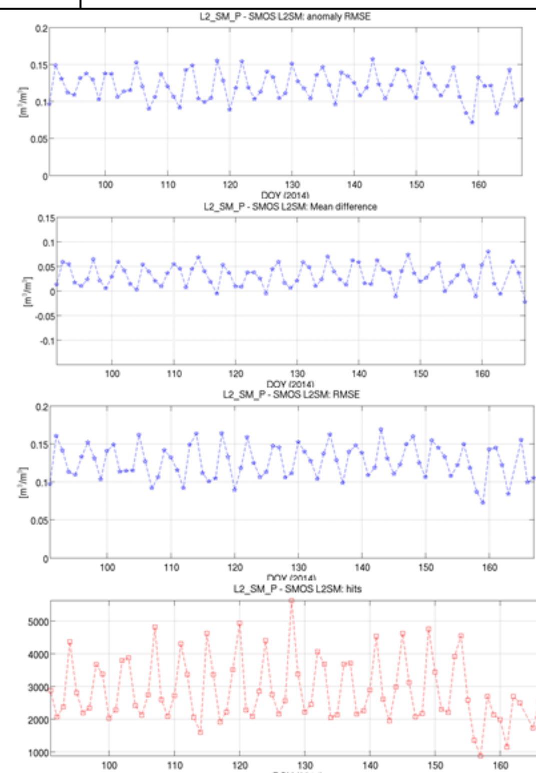


- Spatial and temporal daily match-ups
  - The other product gridded to SMAP grid
  - Acquisitions within 2 hours
- Daily metrics computed



- Metrics as a function of time





- Mean values over the period
  - RMSD: 0.138
  - Bias: 0.044
  - a-RMSD: 0.130

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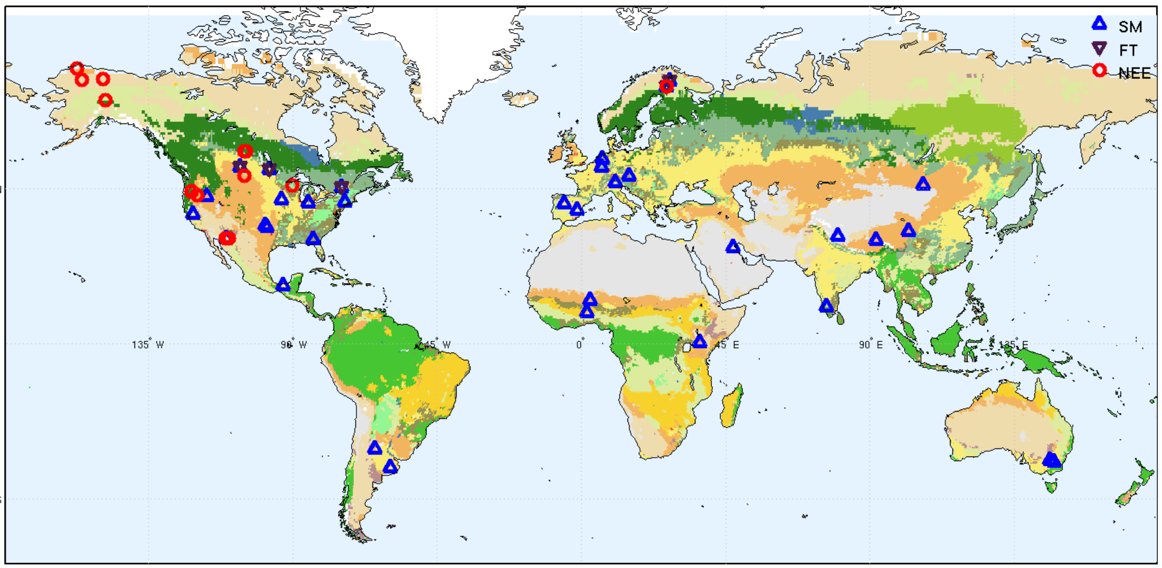
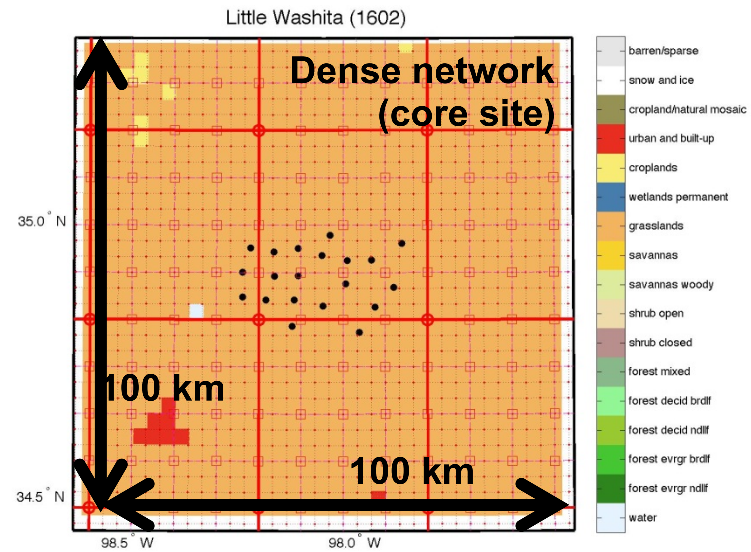
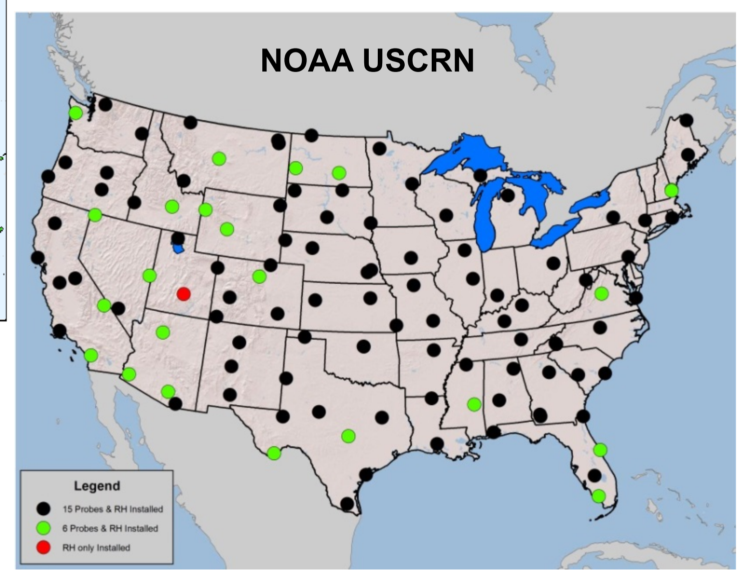
SMAP Soil Moisture Cal/Val Approach

- Primary calibration and validation approach is utilization of dense in situ soil moisture measurements (multiple soil moisture measurement within the 3-km to 36-km SMAP footprint)







- Supplemental approach will utilize large-scale sparse networks (one measurement within footprint), and global remote sensing and model-based soil moisture data products

Cal/Val Partners and Core Contributing Sites

- **Core Validation Sites**: In situ observing sites that provide well-characterized estimates of a soil moisture product at a matching spatial scale, a direct benchmark reference for the products. Additional minimum criteria are:
  - Provides calibration of the in situ sensors
  - Up-scaling strategy provided (implemented by Project)
  - Provides data in a timely manner
  - Long term commitment by the sponsor/host
  - An area that is homogeneous or has a uniform mixture of land covers at the product scale
  - Represents an extensive or important biome and complements the overall set of sites

- **Contributing Validation Sites**: In situ observing sites that provide estimates of a soil moisture product but do not meet all of the minimum criteria for a Core Validation Site. (i.e. sparse networks)
  - Contributing Validation Sites are a resource used to supplement validation results from the Core Validation Sites.

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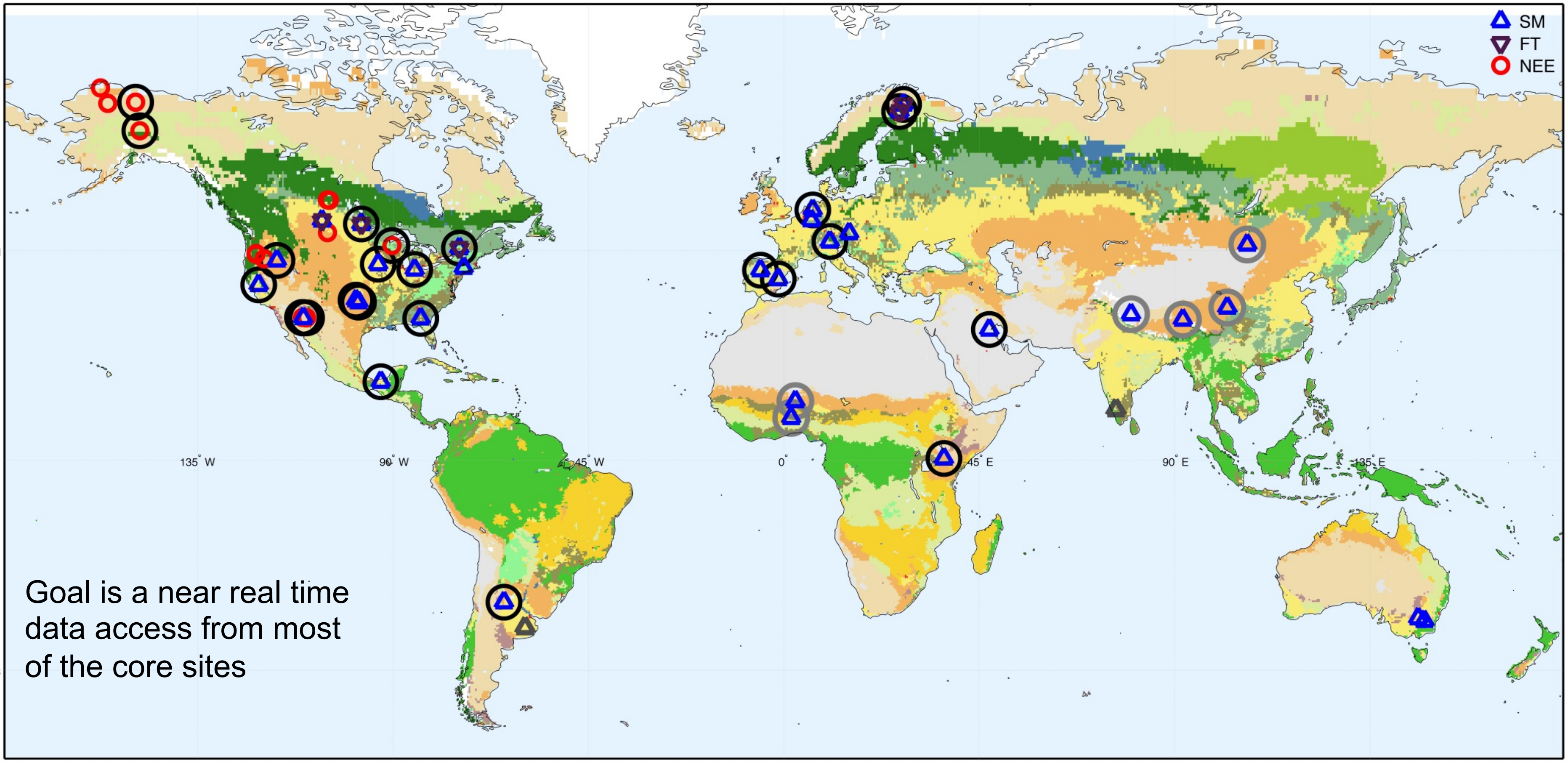
Global Core Validation Sites



Black circles: Near real-time data access established
No circle: Near real-time data access being established (expected to be completed by launch)
Grey circles: No near real-time data access available (data available at the end of Cal/Val Phase)
Grey triangles: installations on-going, but expected to provide useful data at some point during the Cal/Val Phase

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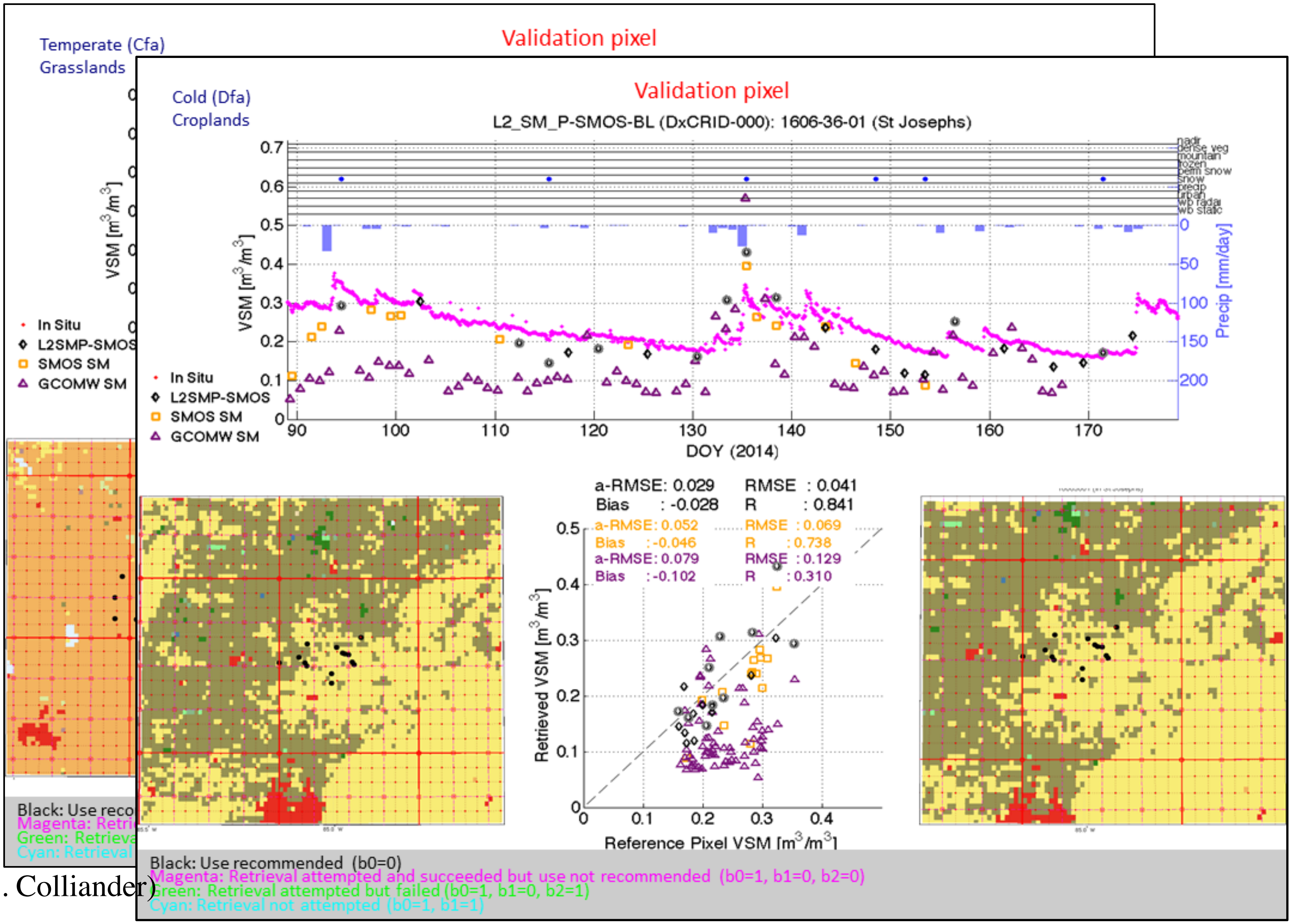
Soil Moisture Satellite Product Comparisons Over Reference Grids



(A. Colliander)

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Role of Airborne Field Campaigns

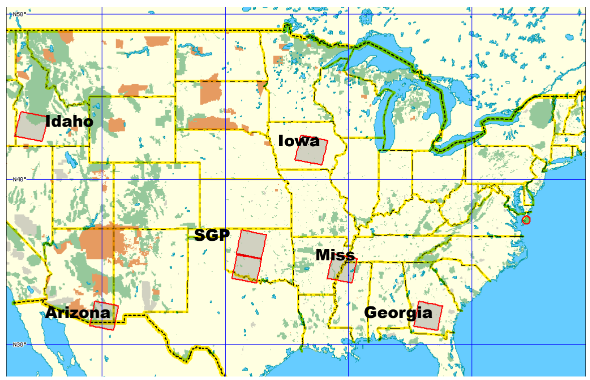
Multi-scale soil moisture field experiments using satellite, airborne, and in-situ sensing

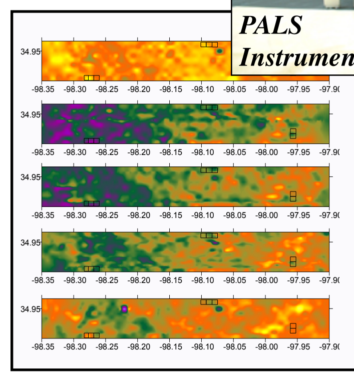
- Coordinated by NASA and USDA/ARS Hydrology Laboratory
- Included flights of PALS and UAVSAR L-band sensors
- Participation by university faculty and students in field measurements and data analysis

NCAR C-130 Aircraft

PALS Instrument

Field Campaign U.S. Sites





SMEX Airborne soil moisture mapping

In-situ Sampling

GLOBE HOME

600+ High-Schools

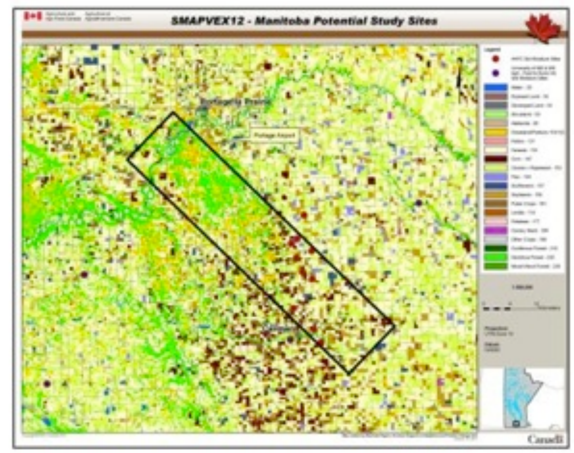
Students collect ground-truth soil moisture data. Classroom access linkages developed for soil moisture mission data.

SMAPVEX12 Field Campaign

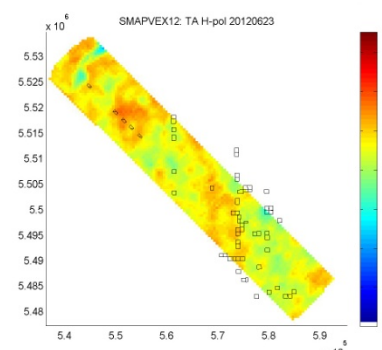
- SMAPVEX12 joint US-Canadian SMAP field campaign conducted in June/July 2012 near Winnipeg, Manitoba in Canada
  - Sites included varied terrain and soil conditions; agriculture, forest, pasture
  - In situ, UAVSAR, and PALS radiometer data have been preprocessed and calibrated
  - Data are in process of being used for algorithm tests and refinement
- Cal/Val partner investigations selected in response to no-exchange-of-funds NASA ROSES solicitation
  - Partners will collaborate to provide validation sites and in situ data for SMAP post-launch science data validation
  - Successful Canadian SMAP Science Workshop was held in Ottawa in March 2013 focusing on Canadian SMAP Cal/Val sites and pre- and post-launch preparations (rehearsals and 2015/16 field campaign)

PALS on Twin Otter

UAVSAR on G-III

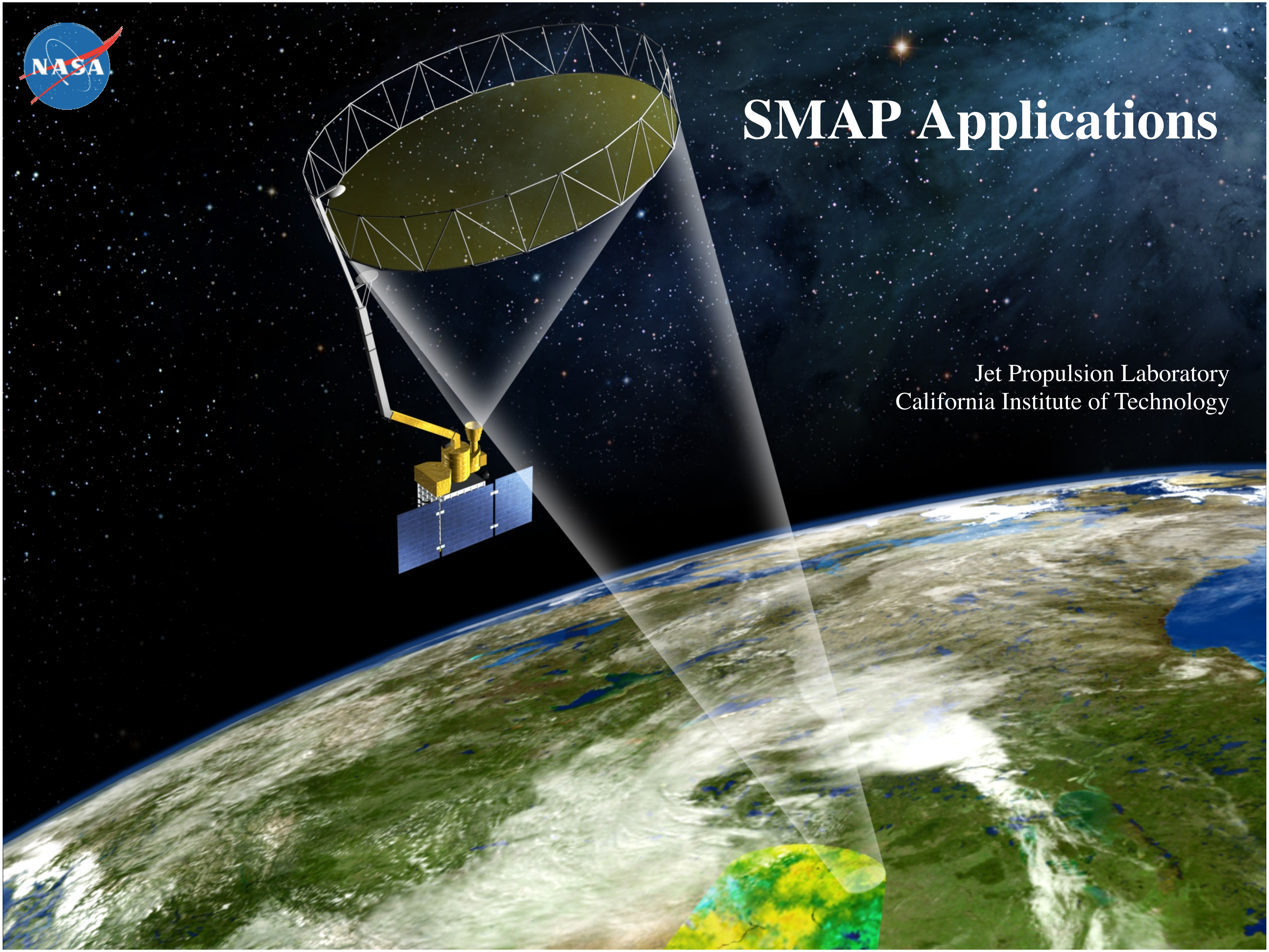


PALS Brightness Temperature



Post-Launch Airborne Sensor Campaigns

- SMAPVEX 2015
  - Walnut Gulch, AZ
    - Convective rainfall produces highly variable spatial soil moisture (Monsoon)
    - Strong evaporative demand results in rapid drydown
- SMAPVEX 2016
  - Carmen, Manitoba
    - Wide variety of agricultural crops at peak growth produces a heterogeneous landscape
  - TBD
    - Based upon analyses in the first 6-9 months, identify sites that are anomalous and can be resolved with a campaign.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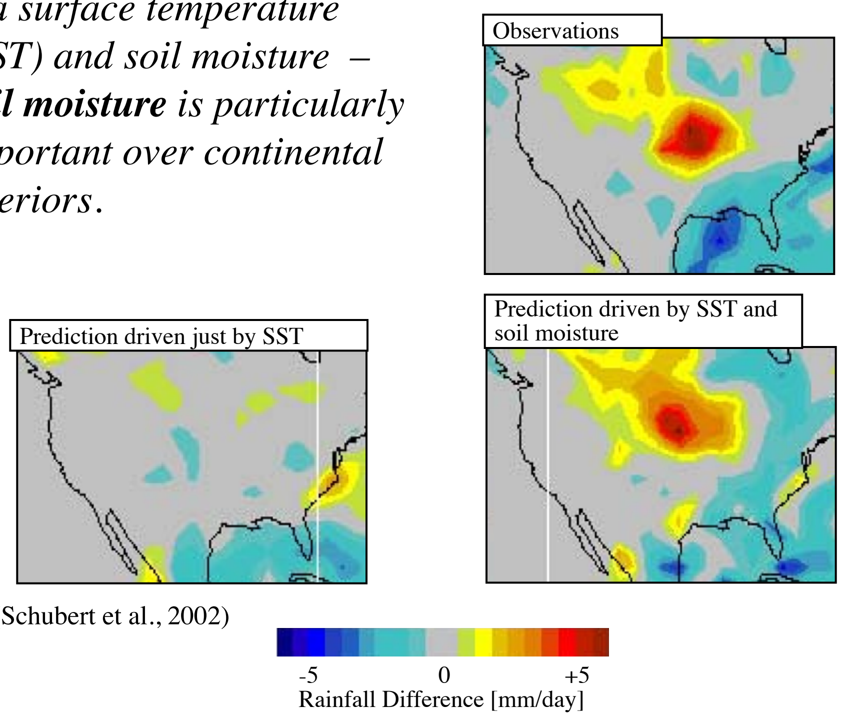
Value of Soil Moisture Data to Weather & Climate

New space-based soil moisture observations and data assimilation modeling can improve forecasts of local storms and seasonal climate anomalies

Seasonal Climate Predictability

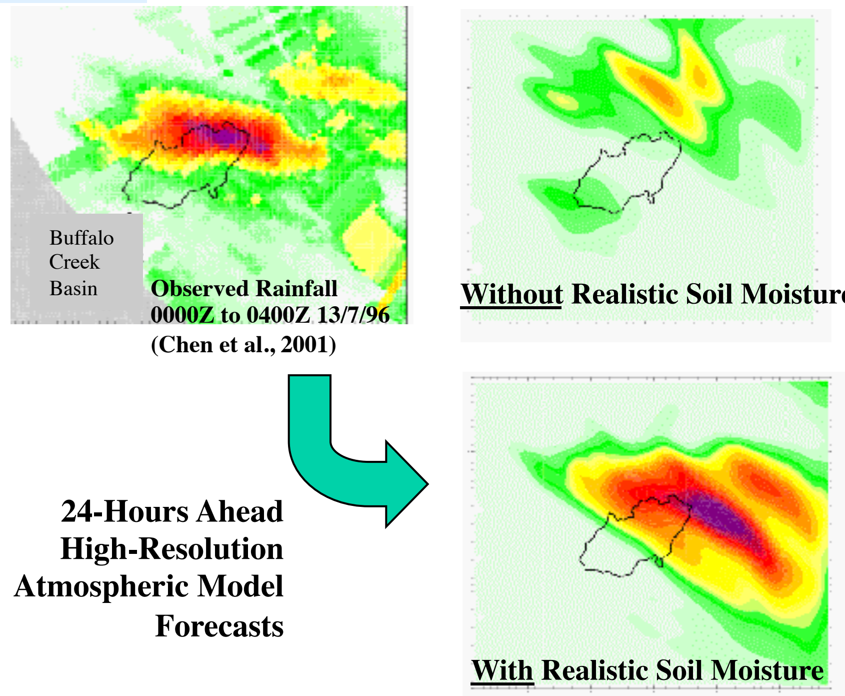
Predictability of ***seasonal climate*** *is dependent on boundary conditions such as sea surface temperature (SST) and soil moisture –* ***soil moisture*** *is particularly important over continental interiors.*

Difference in Summer Rainfall: 1993 (flood) minus 1988 (drought) years



(Schubert et al., 2002)

NWP Rainfall Prediction



In weather forecasting, SMAP surface soil moisture, with x10 higher resolution than existing model estimates, will result in enhanced predictions.

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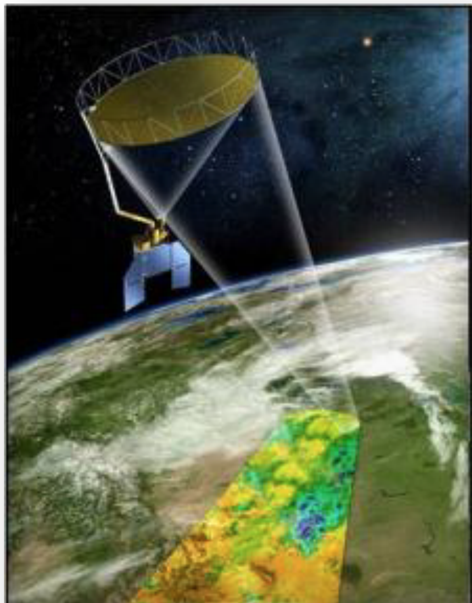
A Flood Example



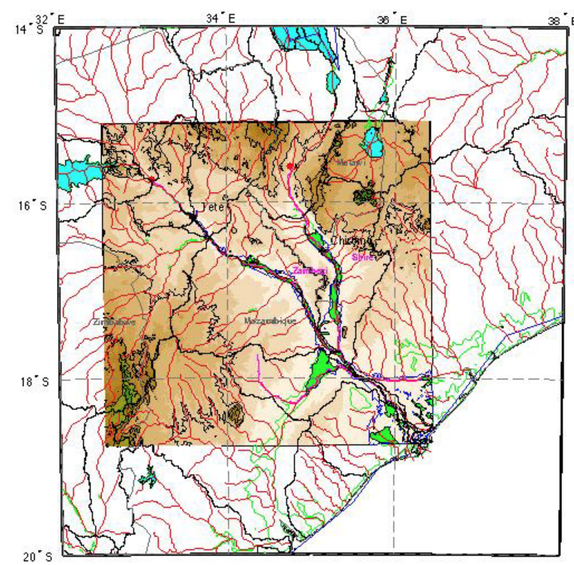
Application of a SMAP-Based Index for Flood Forecasting in Data-Poor Regions

Current Capability: The UN-WFP uses satellite derived flood maps to locate floods and map delivery routes to affected areas.

Enhanced Capability: Use SMAP to expand their current flood database with look-up information that produces flood indices for a given rainfall forecast (ECMWF) and soil moisture condition (SMAP).

Study Area: Zambezi basin and its delta in Mozambique.

Algorithm Structure: VIC output on flow is input into a hydrodynamic model (LISFlOOD-FP), which is complemented with a sub-grid channel formulation to generate flood inundation variables (inundated area, floodplain water volume) for the lower Zambezi basin. ECMWF archived forecast rainfall data is used to compute flows for daily inundation patterns over 10 years.

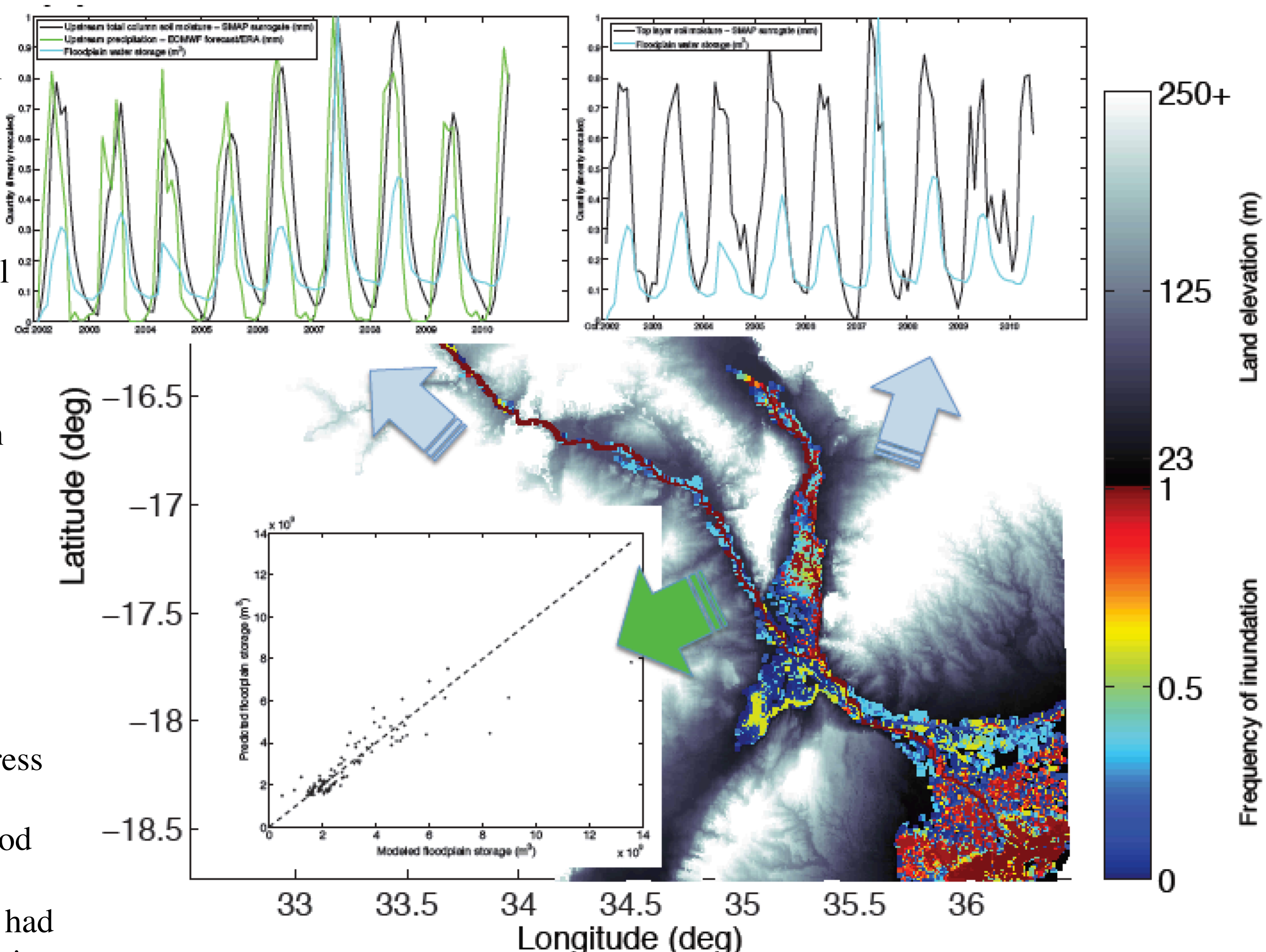


Courtesy of Guy Schumann- UCLA

A Flood Example: Results

Long-term variations in upstream rainfall and soil moisture column vs. floodplain inundation volume (top left panel) and downstream top layer soil moisture (top right panel). Upstream rainfall plus soil moisture 0.88 and rainfall only 0.49.Downstream top layer soil moisture 0.52. The map depicts long-term variations in floodplain inundation patterns from the LISFLOOD-FP flood model. Regression model results for predicting floodplain inundation volume are shown in the bottom left scatter plot.

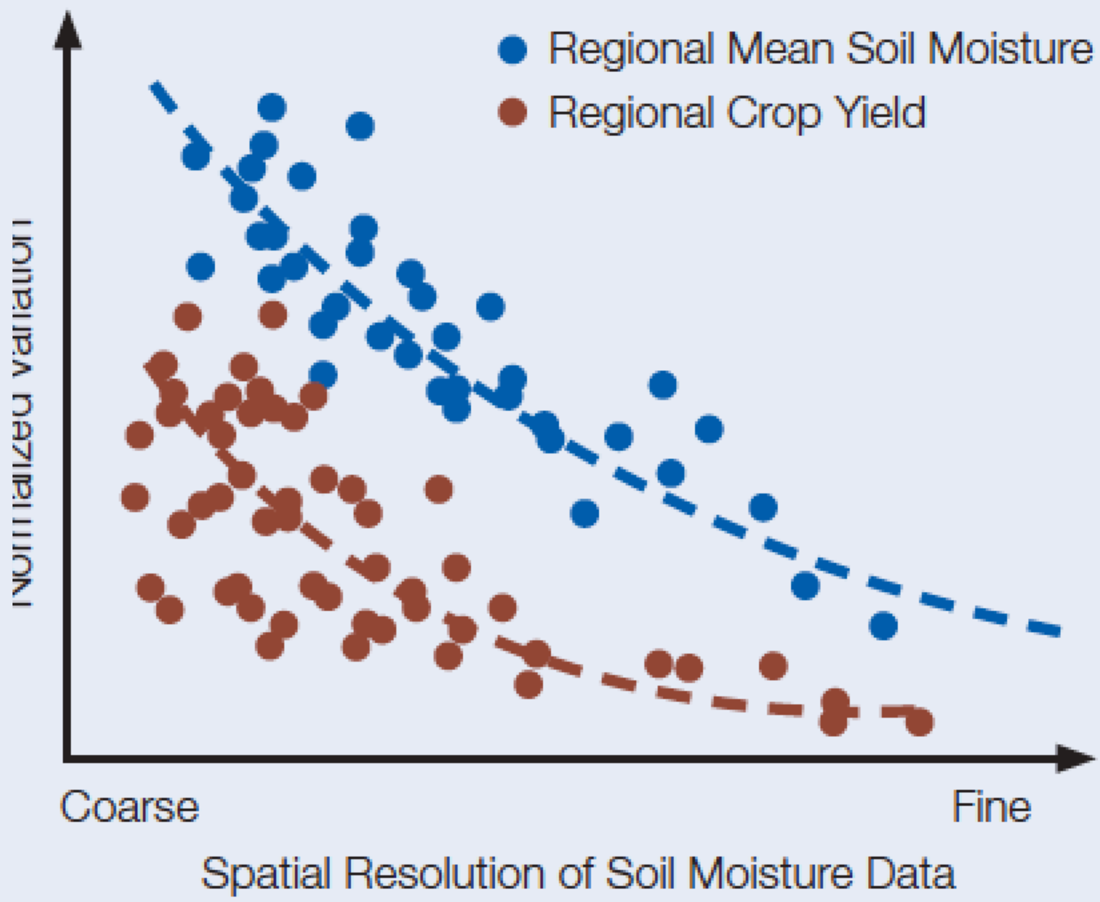
These variables were used to regress and predict floodplain inundation volume for the February 2007 flood event, which was taken out when regressing. The regression model had a relative bias of 17%, with a relative error in predicting the 2007 event of 33%.



Courtesy of Guy Schumann- UCLA

Crop Yield Modeling

Agricultural models have been developed to predict the yield of various crops at field and regional scales. One key input of the agricultural models is soil moisture. The conceptual diagram relates variation in regional domain-averaged soil moisture to variation in total crop yield. Statistical analysis would lead to the development of probability distributions of crop yield as a transformation of the probability distribution of domain averaged soil moisture at the beginning of the growing season.



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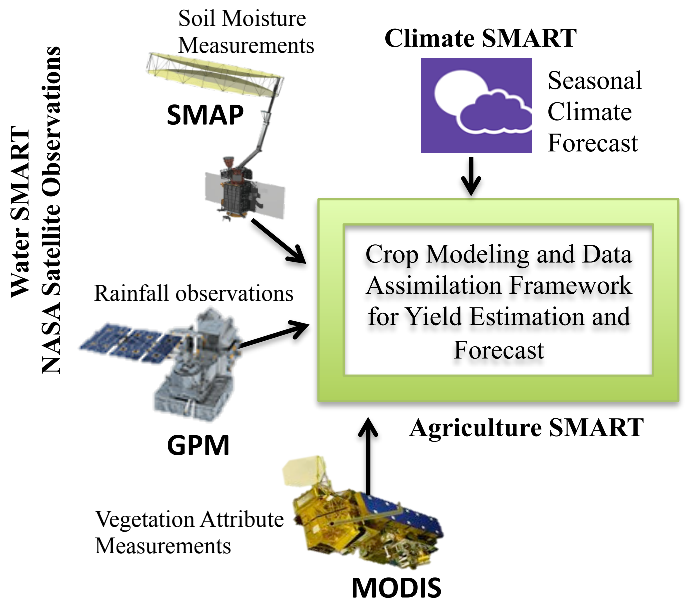
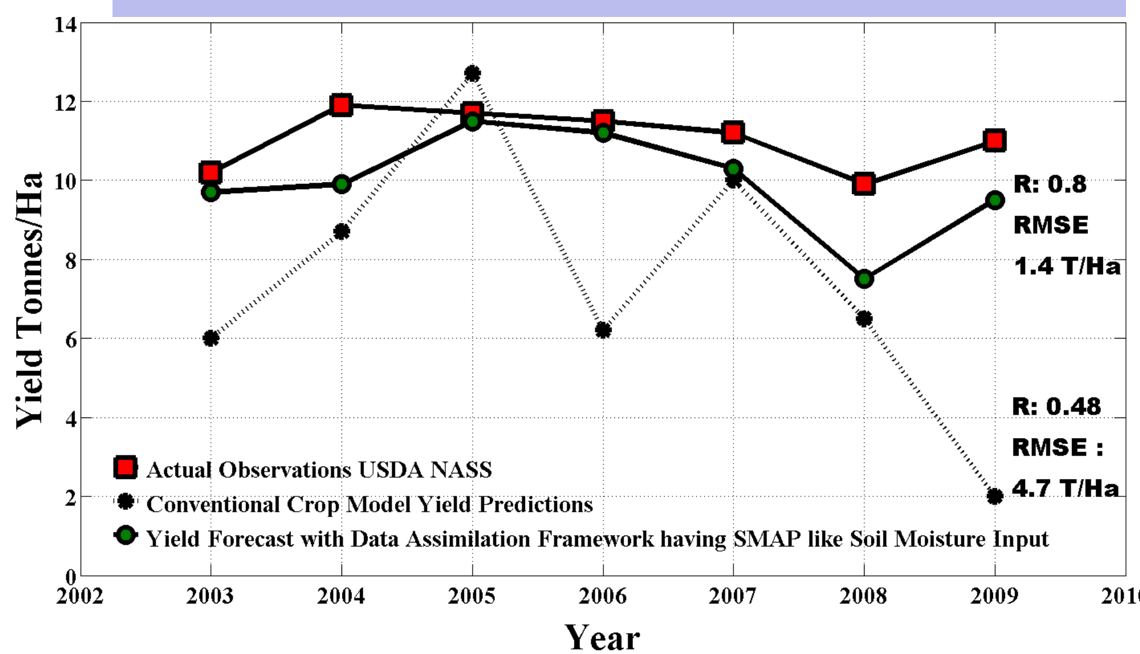
SMAP for Agricultural Crop Yield and Food Security Applications



Statement of Problem: The world faces an uphill struggle in feeding a projected nine to ten billion people by 2050.

Corn Yields with Improved Estimation and Optimal Forecast based on use of SMAP-like Soil Moisture Estimates



Crop Simulation Model for Maize Yield Prediction. RSE-D-12-00872R2: Remote Sensing of Environment, *In Press*

Courtesy of Narendra Das- JPL

<u>Water</u> is the defining link between the climate and agriculture. To improve <u>agricultural drought decision support</u> systems and ensure <u>food security</u>, better quality and better use of <u>Soil Moisture/ Water</u> information is vital.

This information will increase the lead time and skill of of crop yield forecasts.

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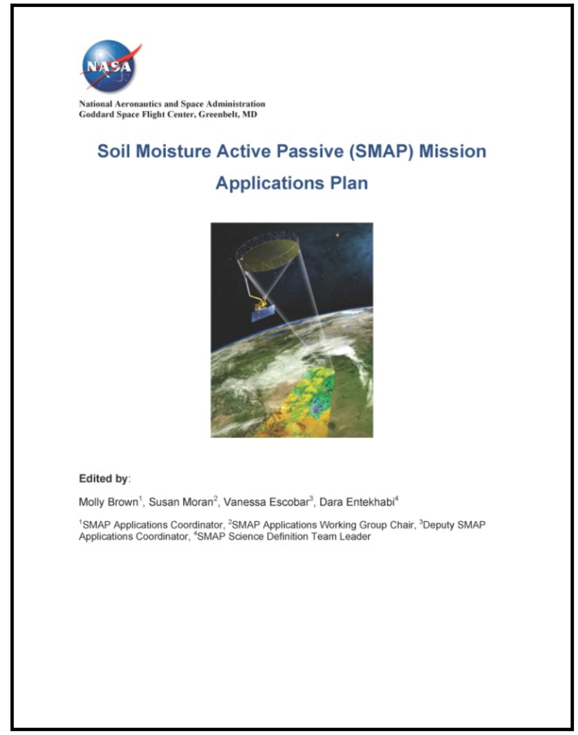
SMAP Applications Development Approach

A primary goal of the NASA SMAP Mission is to engage SMAP end users and build broad support for SMAP applications through a transparent and inclusive process.

Toward that goal, the SMAP Mission:

1. Formed the SMAP Applications Working Group (150+ Members)
2. Developed the SMAP Applications Plan (right)
3. Hired a SMAP Applications Manager
4. Held SMAP Applications Workshops at User Home Sites (e.g., NOAA, USDA, USGS)
5. Developed the "Early-Adopter" Program (30+ Members)


National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD

Soil Moisture Active Passive (SMAP) Mission
Applications Plan

Edited by:

Molly Brown[1], Susan Moran[2], Vanessa Escobar[3], Dara Entekhabi[4]

[1]SMAP Applications Coordinator, [2]SMAP Applications Working Group Chair, [3]Deputy SMAP Applications Coordinator, [4]SMAP Science Definition Team Leader

SMAP Applications Early Adopters

SMAP Early Adopters†, SMAP project contacts, and applied research topics. Many Early Adopters cross multiple applications.	
Early Adopter PI and institution SMAP Contact	**Applied Research Topic**
Weather and Climate Forecasting	
* **Stephane Bélair**, Meteorological Research Division, Environment Canada (EC); SMAP Contact: **Stephane Bélair**	Assimilation and impact evaluation of observations from the SMAP mission in Environment Canada's Environmental Prediction Systems
* **Lars Isaksen and Patricia de Rosnay**, European Centre for Medium-Range Weather Forecasts (ECMWF); SMAP Contact: **Eni Njoku**	Monitoring SMAP soil moisture and brightness temperature at ECMWF
* **Xiwu Zhan, Michael Ek, John Simko and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS); SMAP Contact: **Randy Koster**	Transition of NASA SMAP research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts
* **Michael Ek, Marouane Temimi, Xiwu Zhan and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS), City College of New York (CUNY); SMAP Contact: **Chris Derksen**	Integration of SMAP freeze/thaw product line into the NOAA NCEP weather forecast models
* **John Galantowicz**, Atmospheric and Environmental Research, Inc. (AER); SMAP Contact: **John Kimball**	Use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions
◊ **Jonathan Case, Clay Blankenship and Bradley Zavodsky**, NASA Short-term Prediction Research and Transition (SPoRT) Center; SMAP Contact: **Molly Brown**	Data assimilation of SMAP observations, and impact on weather forecasts in a coupled simulation environment
Droughts and Wildfires	
* **Jim Reardon and Gary Curcio**, US Forest Service (USFS); SMAP Contact: **Dara Entekhabi**	The use of SMAP soil moisture data to assess the wildfire potential of organic soils on the North Carolina Coastal Plain
* **Chris Funk, Amy McNally and James Verdin**, USGS & UC Santa Barbara; SMAP Contact: **Molly Brown**	Incorporating soil moisture retrievals into the FEWS Land Data Assimilation System (FLDAS)
◊ **Brian Wardlow and Mark Svoboda**, Center for Advanced Land Management Technologies (CALMIT), National Drought Mitigation Center (NDMC); SMAP Contact: **Narendra Das**	Evaluation of SMAP soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor (USDM)
◊ **Uma Shankar**, The University of North Carolina at Chapel Hill – Institute for the Environment; SMAP Contact: **Narendra Das**	Enhancement of a Bottom-up Fire Emissions Inventory Using Earth Observations to Improve Air Quality, Land Management, and Public Health Decision Support
Floods and Landslides	
* **Fiona Shaw**, Willis, Global Analytics; SMAP Contact: **Robert Gurney**	A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools and risk indices for insurance and reinsurance purposes

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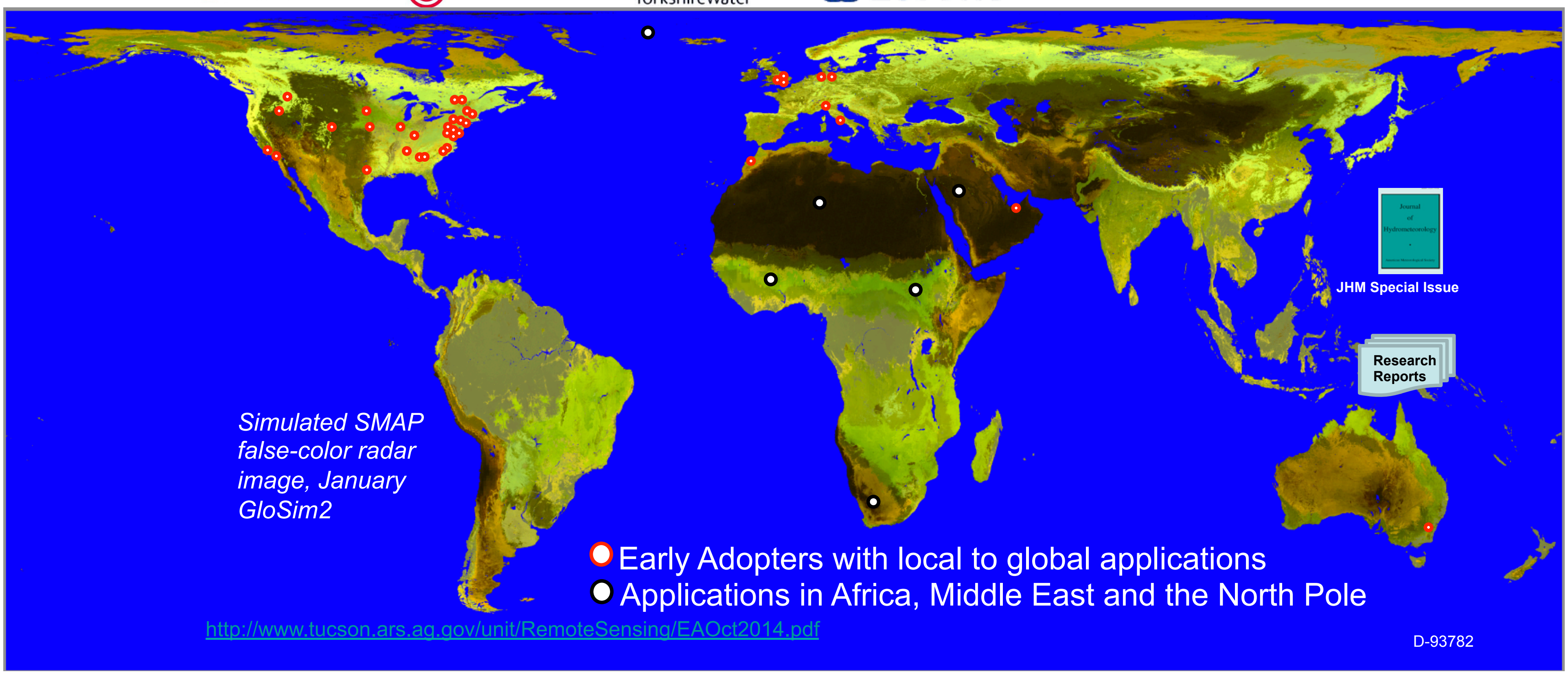
Early Adopters



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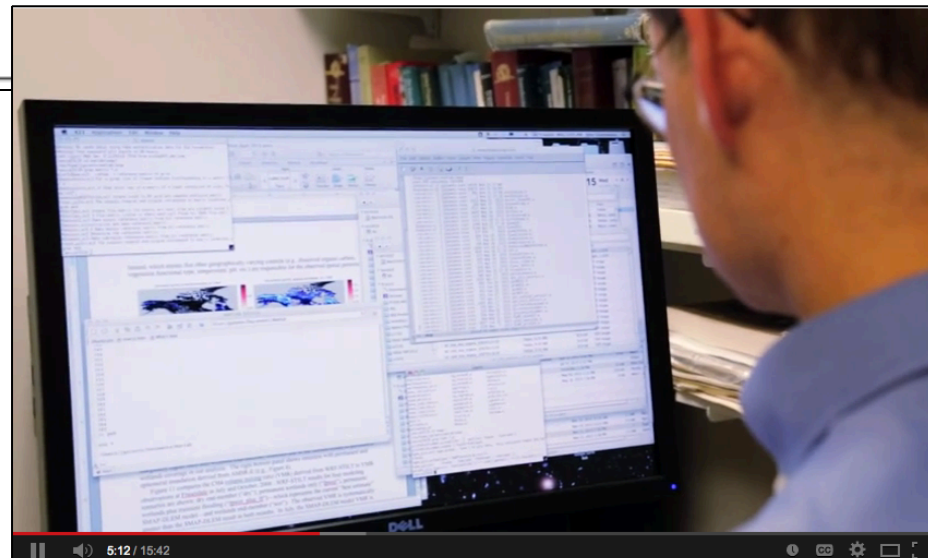
Early Adopter Video

SMAP Early Adopters video

This diverse group represents a cross-section of end-users of SMAP data who collaborate to ensure integration of SMAP data into operations that affect our day-to-day lives. Examples include the U.S. Forest Service, the UN World Food Programme, and the U.S. Department of Agriculture.

VTT files: English (VTT, 18 KB) | Italian (VTT, 18 KB) | Spanish (VTT, 19 KB)

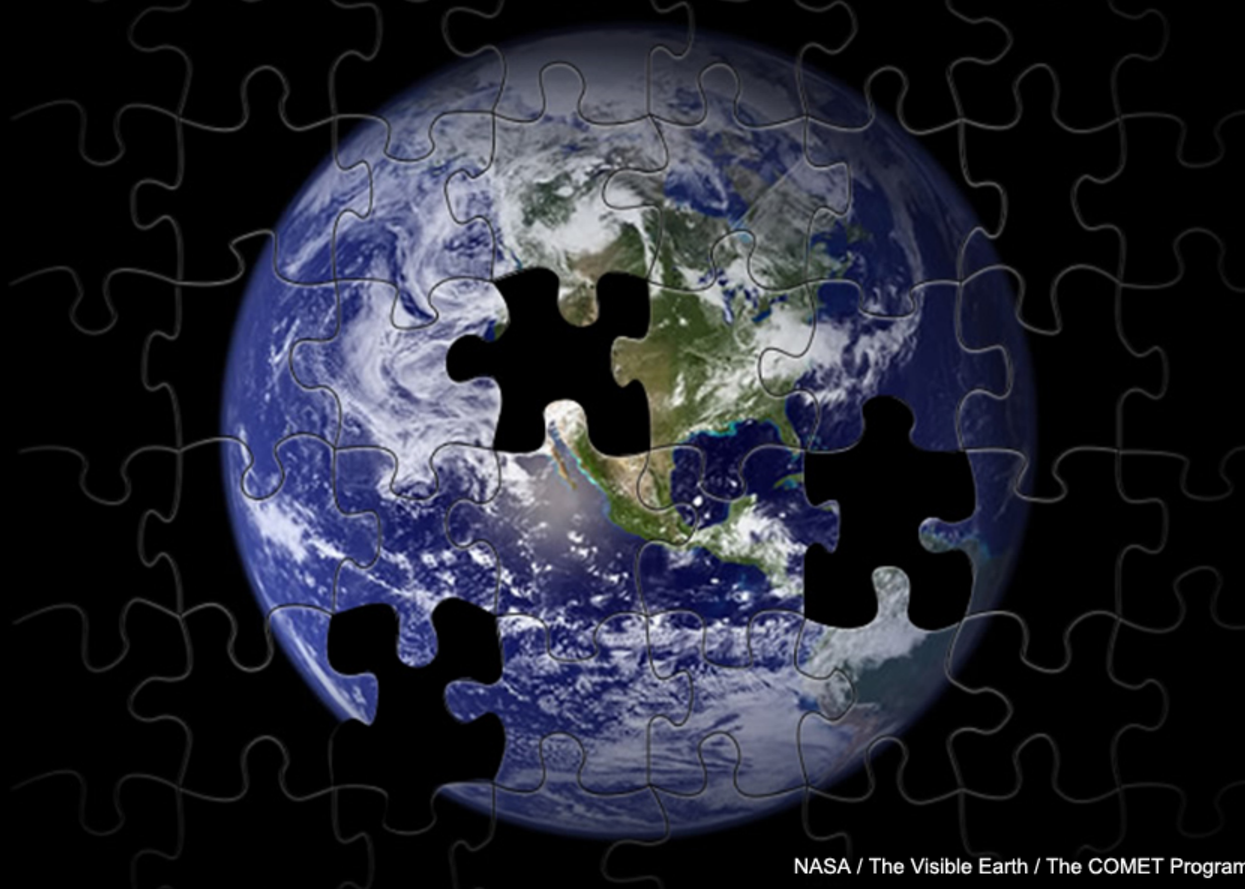
Early Adopters



SMAP Early Adopters

http://smap.jpl.nasa.gov/applications/

SMAP – Part of NASA's Earth Science Program to Better Understand Our Planet



NASA / The Visible Earth / The COMET Program